USA 215

AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE

Volume 13, Number 3, 1998

CAB INTERNATIONAL USA 215
00308346

Alternative Agriculture News

A monthly newsletter available from Henry A. Wallace Institute for Alternative Agriculture

Noted for its succinct yet comprehensive coverage, **Alternative Agriculture News** reports on action by all alternative agriculture groups. It covers:

- Universities and government agencies.
- Non-profit organizations.
- Industry.
- Environmental and farm groups.
- Consumer organizations.
- Private/public sector cooperative efforts.

By reading **Alternative Agriculture News,** you will be well informed about all of the major developments and trends in alternative agriculture.

HERE'S HOW TO SUBSCRIBE:

Rates for INDIVIDUAL Subscribers:

Alternative Agriculture News:
(12 issues)

$16 - U.S.
$21 - Canada & Mexico
$22 - Other Countries

American Journal of Alternative Agriculture:
(4 issues)

$24 - U.S.
$27 - Canada & Mexico
$28 - Other Countries

Combination Subscription:
Journal & Newsletter

$35 - U.S.
$43 - Canada & Mexico
$45 - Other Countries

NOTE: ½ price for students with copy of student I.D.

Rates for LIBRARY subscriptions:

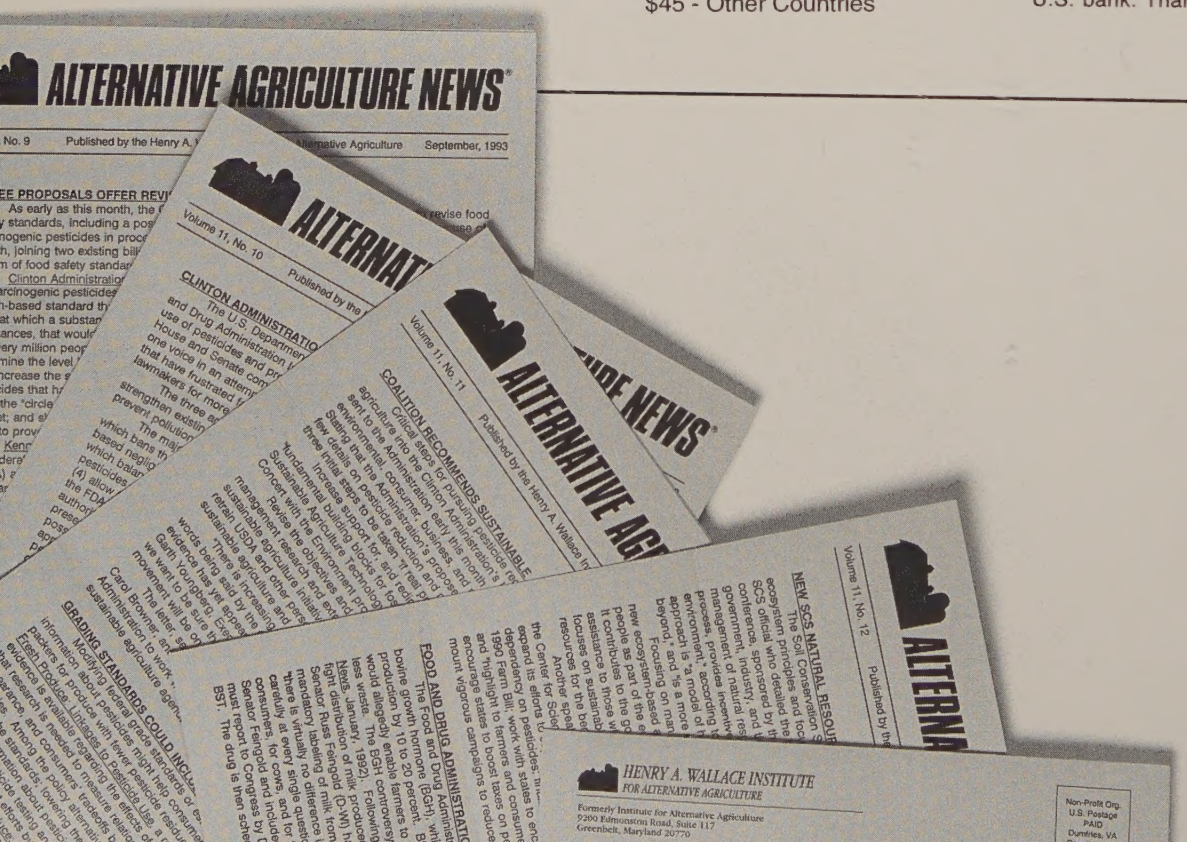
$44 - U.S.
$52 - Canada & Mexico
$54 - Other Countries

Please send a check payable to the:

Wallace Institute
9200 Edmonston Road, Suite 117
Greenbelt, Maryland 20770-1551

Outside USA:

Please pay with postal money order or check drawn on a U.S. bank. Thank You!



CABI BIOSCIENCE
MICHAEL WAY LIBRARY
05 MAR 1999

AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE®

1998
Volume 13, Number 3

TABLE OF CONTENTS

Articles

98 **Alternative practices for managing plant-parasitic nematodes** • Robert McSorley

105 **Impact of agricultural management on nitrate concentrations in drainage waters** • Walter A. Goldstein, Michael J. Scully, Daniel H. Kohl, and Georgia Shearer

111 **Assessment of legume and nonlegume ground covers on Coleoptera: Coccinellidae density for low-input pecan management** • Natasha R. Rice, Michael W. Smith, Raymond D. Eikenbary, Don Arnold, W. Louis Tedders, Bruce Wood, B. Scott Landgraf, Glenn G. Taylor, and Gordon E. Barlow

124 **Agronomic and economic performance of wheat and canola-based double-crop systems** • Emily E. Pullins and Robert L. Myers

132 **Soil Improvement Following Addition of Chipped Wood from Twigs** • Roger Lalande, Valentin Furlan, Denis A. Angers, and Gilles Lemieux

138 **Examination of some microbiological and biochemical parameters and tests of product quality used in a long-term fertilization trial** • Joachim Raupp

Departments

Upcoming Events—123 • Resources—144

Journal Editorial Board

Miguel A. Altieri, University of California at Berkeley • Molly D. Anderson, Tufts University • Lloyd A. Andres, USDA-ARS • M. (Charlie) Arshad, Agriculture and Agri-Food, Canada • David F. Bezdicek, Washington State University • Harold F. Breimyer, University of Missouri • Michael C. Brumm, University of Nebraska • Frederick H. Buttel, University of Wisconsin • Eliot Coleman, Harborside, Maine • Kenneth A. Cook, Center for Resource Economics, Washington, DC • R. James Cook, USDA-ARS • John W. Doran, USDA-ARS • Sara Ebenreck, St. Mary's College • Thomas C. Edens, Michigan State University • Frank P. Eggert, University of Maine • Lloyd F. Elliot, USDA-ARS • A. Dale Flowerday, Lincoln, Nebraska • Charles A. Francis, University of Nebraska • Stephen R. Gliessman, University of California at Santa Cruz • Joan Gussow, Columbia University • Richard R. Harwood, Michigan State University • Glenn A. Helmers, University of Nebraska • Sharon B. Hornick, International Nature Farming Research Center, Bellingham, Washington • Larry D. King, North Carolina State University • Dietrich Knorr, University of Delaware • J. Patrick Madden, World Sustainable Agriculture Association • Robert H. Miller, University of Rhode Island • James F. Parr, International Nature Farming Research Center, Bellingham, Washington • Richard L. Ridgway, USDA-ARS • Douglas L. Young, Washington State University • Raymond R. Weil, University of Maryland

Wallace Institute Board of Directors

Dr. Cornelia Butler Flora, President, Ames Iowa • Mrs. Jean Wallace Douglas, Honorary President, Washington, DC • Dr. Frederick R. Magdoff, Vice President, Burlington, Vermont • Ms. Christine A. (Cass) Peterson, Secretary, Warfordsburg, Pennsylvania • Mr. Jose J. Montenegro, Treasurer, Salinas, California • Dr. Neil V. Anderson, Manhattan, Kansas • Dr. Jill Shore Auburn, Davis, California • Mr. Paul W. Johnson, Decorah, Iowa • Dr. Desmond A. Jolly, Davis, California • Dr. Frederick L. Kirschenmann, Windsor, North Dakota • Dr. Deborah A. Neher, Toledo, Ohio • Dr. Robert I. Papendick, Pullman, Washington • Dr. Frederick V. Payton, Bainbridge, Georgia • Mr. James H. Stephenson, Washington, North Carolina

Journal Staff

Editor in Chief—Garth Youngberg
Editor—Robert I. Papendick
Associate Technical Editors—Marion E. Simpson
—David E. Ervin
Book Review Editor—James F. Parr
Assistant to the Editor in Chief—Sarah C. Byler
Circulation—Joanna L. Hildebrand
—Nancy L. Ward
Art Director—Randy White

The American Journal of Alternative Agriculture (ISSN 0889-1893) is published quarterly by the Henry A. Wallace Institute for Alternative Agriculture, Inc., 9200 Edmonston Road, Suite 117, Greenbelt, Maryland 20770-1551, in collaboration with the Department of Crop and Soil Sciences, Washington State University, Pullman, Washington 99164-6420. Neither the Wallace Institute nor Washington State University is responsible for statements and opinions expressed by authors.

Subscription Information

Annual Journal subscription rates: Library $44—US; $52—Canada and Mexico; $54—all other countries. Individuals $24—US; $27—Canada and Mexico; $28—all other countries. Students $12—US; $13.50—Canada and Mexico; $14—all other countries. Second Class postage paid at Greenbelt, MD. Postmaster: Send address changes to American Journal of Alternative Agriculture, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770-1551.

Wallace Institute Information

The Henry A. Wallace Institute for Alternative Agriculture is a nonprofit, tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of cost-effective, resource-conserving and environmentally-sound farming methods. It works closely with producer groups, public research and education institutions, and government agencies in promoting a sustainable agriculture system.

Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

Two-row plots of various soybean cultivars showing different levels of tolerance to the root-knot nematode (*Meloidogyne incognita*). Photo provided by Robert McSorley.

Alternative practices for managing plant-parasitic nematodes

Robert McSorley

Abstract. *The most widely used and successful cultural practices for managing plant-parasitic nematodes are resistant cultivars and some elements of cropping systems, such as rotation crops, cover crops, or nematode-antagonistic crops. Exclusion and sanitation practices, such as use of nematode-free planting material, site selection, and weed management, are useful in limiting infestations. Soil solarization, organic amendments, biological control, fallow, flooding, timing of planting dates, or tillage practices may be helpful in some areas, but additional research is needed to optimize their use. Most management methods emphasize reduction of nematode populations, but improvement of crop tolerance to nematodes should not be overlooked. For their successful use, most of these alternative methods require detailed knowledge of nematode and plant biology and ecology, and it may be necessary to integrate several practices for maximum nematode suppression. Although the basic principles of nematode management are generally known, detailed data often are lacking on specific combinations of nematodes and host crop cultivars. Consequently, the availability of such data will likely determine whether nematodes can be managed successfully in a particular situation.*

Key words: cropping systems, cultural practices, host-plant resistance, integrated pest management, sustainable agriculture

Plant-parasitic nematodes cause serious losses in many important agricultural crops (Sasser and Freckman, 1988), and managing them effectively can be critical in infested sites. Interest in nonchemical management methods has increased greatly in the past few years because of increased interest in organic production practices (Ferguson and Mesh, 1997) and anticipated restrictions on methyl bromide and other chemical nematicides (Noling and Becker, 1994). Several alternative methods can be used for managing plant-parasitic nematodes (Johnson, 1982; Trivedi and Barker, 1986; Duncan, 1991; Nyczepir, 1991; Weischer, 1994; McSorley and Duncan, 1995). The utility of many of these methods has been recognized for many years (Watson, 1921), but usage was de-emphasized once chemical nematicides became widely available. Today, there is renewed interest in developing and improving these nonchemical methods and cultural practices (Weischer, 1994). Many of them may not reduce nematode populations immediately, as happens with soil fumigation, and most require a much more thorough understanding of nematode biology. However, many alternative practices can be used selectively against key nematode pests, with less adverse environmental impact and at lower cost than the use of soil fumigants.

Florida Agricultural Experiment Station Journal Series No. R-05911.

Robert McSorley is Professor of Entomology and Nematology, University of Florida, Gainesville, FL 32611-0620; rmcs@gnv.ifas.ufl.edu.

Host-Plant Resistance

The use of resistant cultivars is the most important method for managing plant-parasitic nematodes. Cultivars with some degree of resistance to one or more nematode species are available in many crops and have proven very effective in nematode management (Sasser and Kirby, 1979; Fassuliotis, 1982, 1987; Roberts, 1982, 1992; Cook and Evans, 1987; Trudgill, 1991; McSorley and Duncan, 1995; McSorley, 1996). Resistance has been particularly useful against sedentary endoparasitic nematode genera such as *Globodera, Heterodera, Meloidogyne,* and *Tylenchulus,* because of their highly specialized life cycles and feeding habits (Taylor and Sasser, 1978; Sasser and Kirby, 1979; Fassuliotis, 1982; Cook and Evans, 1987; Roberts, 1992). Many nematologists use the terms resistance and susceptibility to refer to the relative degree of nematode reproduction on the host plant (Cook and Evans, 1987; Trudgill, 1991). Some plants may be immune to a particular nematode species, allowing no reproduction. However, resistance often is not all-or-nothing, and various levels of nematode reproduction may occur even on relatively resistant hosts. In addition, the rate of reproduction may vary with the nematode population density (Seinhorst, 1970). Therefore, the relationship between nematode population growth and population density usually provides the best description of resistance or susceptibility of a given host. If one cultivar is more resistant or less susceptible than another, then its use may still provide important practical benefits even if resistance is not complete.

Table 1 gives a few examples of crop plants with cultivars showing various degrees of resistance to their most serious nematode pests. Such instances of relative differences in susceptibility or resistance among crop cultivars are widespread, and many more examples may be discovered

Table 1. Some examples of crop species with cultivars resistant to their most serious nematode pests.

	Crop	Nematode	References
potato	*Solanum tuberosum*	*Globodera* spp.	Trudgill 1991; Brodie et al. 1993
citrus rootstocks	*Citrus* spp.	*Tylenchulus semipenetrans*	Duncan & Cohn 1990
tomato	*Lycopersicon esculentum*	*Meloidogyne* spp.	Sasser & Kirby 1979; Fassuliotis 1987
soybean	*Glycine max*	*Heterodera glycines*	Riggs & Niblack 1993
tobacco	*Nicotiana tabacum*	*Meloidogyne* spp.	Sasser & Kirby 1979
wheat and other small grains	*Triticum aestivum*	*Meloidogyne* spp. *Heterodera avenae*	Johnson & Motsinger 1989 Cook and Evans 1987; Rivoal & Cook 1993
grape	*Vitis vinifera*	*Meloidogyne* spp.	Brown et al. 1993
peach rootstocks	*Prunus persica*	*Meloidogyne* spp.	Nyczepir 1991
plum rootstocks	*Prunus domestica*	*Meloidogyne* spp.	Nyczepir 1991
many vegetables		*Meloidogyne* spp.	Sasser & Kirby 1979; Fassuliotis 1987

by future research. Among the thousands of cultivated crops and cultivars available, there are probably many with nematode resistance that have not been identified. Screening programs are needed to discover these, and breeding programs are needed to combine resistance with other useful characteristics (Cook and Evans, 1987). It is important to test a range of cultivars on a local level to identify those that will be most effective in a specific situation.

An important limitation in the use of nematode-resistant cultivars is that a cultivar resistant to one nematode species or race may not be resistant to others. Therefore, effective use of resistance depends on identifying the nematode species, races, or even isolates present in a particular field (Taylor and Sasser, 1978; Schmitt and Barker, 1988; Carpenter and Lewis, 1991). Temperature and other environmental factors may affect the expression of resistance (Dropkin, 1969; Seinhorst, 1970; Cook and Evans, 1987). Judicious management of host-plant resistance is critical to avoid selection for resistance-breaking nematode pathotypes (Cook and Evans, 1987; McSorley and Duncan, 1995).

Cropping Systems

Because nematodes cannot migrate quickly from field to field, the rise and fall of nematode populations will depend on the relative resistance or susceptibility of any crop or sequence of crops grown in a given field. Cropping systems can be devised to minimize the impact of nematodes while maintaining long-term productivity (Nusbaum and Ferris, 1973; Noe, 1988; Barker, 1991; Noe et al., 1991; McSorley and Gallaher, 1992; McSorley and Duncan, 1995). Cropping systems may include crop rotations, cover crops and intercrops, nematode-antagonistic crops, and summer or winter fallow to reduce nematode populations.

Crop rotation

The usefulness of crop rotation for reducing nematode populations has long been recognized (Good, 1968; Nusbaum and Ferris, 1973; Johnson, 1982; Trivedi and Barker, 1986). For example, the soybean-cyst nematode (*Heterodera glycines*) has been managed successfully in the midwestern and southeastern United States by rotation with corn (*Zea mays*) or other nonhost crops (Schmitt, 1991; Riggs and Niblack, 1993). Crop rotations to manage the cereal-cyst nematode (*Heterodera avenae*) may require at least two years between susceptible cereal crops (Smiley, 1996), and an even longer break may be required with highly persistent pests such as potato-cyst nematodes (*Globodera* spp.) (Brodie et al., 1993).

The practical use of any rotation crop will depend on its economics and adaptability in a specific region. Ideally, sequences that alternate susceptible and nonsusceptible crops can be planned to minimize nematode population size and damage (Trivedi and Barker, 1986; Noe, 1988; Noe et al., 1991). Detailed data on nematode population dynamics across a range of population densities are useful for this approach (Seinhorst, 1970). In addition, information on economic thresholds and relationships between crop growth and nematode densities are necessary for assessing the profitability of alternative crop sequences (Seinhorst, 1970; Noe et al., 1991). Although basic data on population dynamics (Seinhorst, 1970; McSorley and Phillips, 1993) and thresholds (Barker and Noe, 1987; McSorley and Phillips, 1993; McSorley and Duncan, 1995) are available for many nematode-crop combinations, they are unavailable for many situations, which limits the opportunity to design cropping systems. In most locations, more data are needed on the susceptibility of crops and cultivars to local nematode populations to expand the choice of useful rotation crops. Design and implementation of crop rotation systems can become more complex when several damaging nematode species are present in the same site, because a crop effective against one species may be a good host for another (McSorley et al., 1994).

Cover crops

During the times of the year when the main agricultural crop is not being grown, cover crops may be grown for forage, as an additional source of income, or to improve soil conditions. They also have important implications for nematode management, since nematode populations in the site will

continue to rise or fall depending on the suitability of the cover crop as a host (Rhoades, 1983; McSorley and Gallaher, 1992; McSorley, 1996). Winter cover crops of wheat or other small grains may be helpful in suppressing root-knot nematodes (Opperman et al., 1988; McSorley and Gallaher, 1992). Certain cultivars of sorghum (*Sorghum bicolor*) and sorghum-sudangrass (*S. bicolor x S. sudanense*) have been used as summer cover crops in Florida to suppress *Meloidogyne* spp. or *Rotylenchulus reniformis*, but were not effective against *Belonolaimus longicaudatus* or *Paratrichodorus minor* (Rhoades, 1983; McSorley et al., 1994; McSorley, 1996).

Intercropping

Maintaining crop diversity through intercropping has been helpful in managing insects (Vandermeer, 1990), but it has had only limited success with nematodes. Nematodes were reduced by interplanting susceptible crops with marigolds (Khan et al., 1971), but in another study, nematodes reproduced on the roots of an interplanted host crop (Hackney and Dickerson, 1975). For nematode management, maintaining crop diversity over time, that is, crop sequences, is probably much more important than maintaining diversity in space through intercropping (Flint and Roberts, 1988).

Antagonistic crops

Recently, attempts have been made to introduce nematode-antagonistic or nematode-suppressive crops into some locations in the southeastern United States for cover or rotation crops (Rodriguez-Kabana et al., 1989; McSorley et al., 1994). Some plants tested for this purpose include castor (*Ricinus communis*), crotalaria (*Crotalaria spectabilis*), hairy indigo (*Indigofera hirsuta*), jointvetch (*Aeschynomene americana*), marigold (*Tagetes* spp.), pangola grass (*Digitaria decumbens*), partridge pea (*Cassia fasciculata*), Rhodes grass (*Chloris gayana*), sesame (*Sesamum indicum*), sunn hemp (*Crotalaria juncea*), and velvetbean (*Mucuna deeringiana*) (Good, 1968; Brodie et al., 1970; Reddy et al., 1986; Rodriguez-Kabana et al., 1988, 1989; Rodriguez-Kabana, 1992; Caswell et al., 1991; McSorley et al., 1994; McSorley and Dickson, 1995).

Some of these plants may be suppressive because they are nonhosts of certain nematodes, but in others, such as marigold, chemical products active against nematodes have been identified in root exudates (Huang, 1985). However, even for a suppressive plant such as marigold, the effects on *Meloidogyne* spp. depend on the cultivar used (Rickard and Dupree, 1978). Populations of *B. longicaudatus* and several other nematodes increased on a marigold cultivar that was resistant to *M. incognita* (Rhoades, 1980). Although antagonistic crops may be effective for nematode management, most of them have limited economic value, some are considered weeds (crotalaria, hairy indigo, partridge pea), and a few are toxic to poultry and livestock (castor, crotalaria).

Fallow and flooding

Since the lack of a suitable host affects nematode populations, clean fallow or flooding may be useful in some situations (Trivedi and Barker, 1986; Weischer, 1994; McSorley and Duncan, 1995). Clean fallow is essential; if any weeds are present they may allow nematode populations to increase (McSorley and Gallaher, 1992). Disadvantages of clean fallow include erosion and other adverse effects on soil structure, lack of income during fallow, and the time involved for the fallow period (Trivedi and Barker, 1986). Flooding also may be impractical in many situations, since it may be necessary to maintain the flood for two to three months to reduce nematode populations, and even longer to affect the viability of eggs (Maas, 1987).

Biological Control and Organic Amendments

Many natural enemies, including fungi, bacteria, nematodes, mites and other microarthropods, and several other kinds of organisms are known predators or parasites of nematodes (Small, 1987; Walter et al., 1988; Stirling, 1991). Many of these have been found in most soils surveyed (Gray, 1987; Rodriguez-Kabana and Morgan-Jones, 1988), and it seems likely that some degree of natural biological control of nematodes occurs in most soils. It is difficult to assess the efficacy of natural biological control, although the population declines associated with specific antagonists have been documented (Stirling, 1991).

One approach to making better use of biological control has attempted, with varying degrees of success, to mass produce organisms such as the bacterium *Pasteuria penetrans* or certain nematode-antagonistic fungi for eventual field release (Kerry, 1984, 1990; Jaffee et al., 1990; Stirling, 1991; Tedford et al., 1993). Another approach has been to try to enhance the soil environment for development of nematode antagonists, such as by addition of organic amendments (Muller and Gooch, 1982; Rodriguez-Kabana, 1986; Kerry, 1990; Stirling, 1991; McSorley and Duncan, 1995).

The results achieved with organic amendments sometimes have been contradictory and controversial, and interpretation can be difficult because the amendment often also affects plant growth directly, apart from any effects on the nematode population. Nematode populations may be reduced by toxic decomposition products or possibly by stimulation of nematode antagonists. However, evidence for a precise mode of action can be difficult to obtain, and the precise mechanisms and conditions by which nematode predators and parasites can reliably be increased are not well understood (Stirling, 1991). Amendments with low C:N ratios that release ammonia tend to be more effective against nematodes (Rodriguez-Kabana, 1986). However, their efficacy depends not only on C:N ratio, but also on amendment type, composition, amount of material used, composition of the soil antagonist and decomposer communities (about which little is known), application method, and environmental conditions. When the effects of these factors are better understood, more consistent results with organic amendments may be obtained. Potential organic products should be tested carefully in a location before they are used extensively for nematode management. Data on nematode population densities are essential in establishing efficacy. Neither yield

nor plant growth data alone are sufficient for evaluating activity against nematodes.

Other Strategies

Exclusion and sanitation

Prevention of nematode infestations in a site is an important first line of defense against these pests. Because they are small and have limited mobility, nematodes have difficulty in colonizing new sites unless they are introduced on infested plants, soil, or equipment. On a local scale, selection of uninfested sites and use of pest-free planting materials are critical (Trivedi and Barker, 1986; Nyczepir, 1991), while on a regional scale, quarantines are important in preventing infestation and spread (Maas, 1987). Heat treatment is generally used for disinfesting planting material or small quantities of soil or potting media (Maas, 1987; McGovern and McSorley, 1997). Once nematodes have been introduced into a site, destruction of infested crop residues and weed hosts may be helpful in limiting their spread (Trivedi and Barker, 1986; Nyczepir, 1991).

Tolerance and maintenance of plant health

Most management methods emphasize reduction of nematode populations, but improving plant tolerance is an alternative approach to minimizing crop damage. It is well established that the amount of damage is related to nematode density (Seinhorst, 1970; Barker and Noe, 1987; McSorley and Phillips, 1993; McSorley and Duncan, 1995), but some plant cultivars may be more tolerant of the same nematode population density than others (Trudgill, 1991).

Selection and use of tolerant germplasm is important, and should not be overlooked by plant breeders (Seinhorst, 1970; Cook and Evans, 1987), but environmental conditions also may influence plant tolerance. Improved maintenance of infected plants through increased nutrition (Trivedi and Barker, 1986), water (Trivedi and Barker, 1986; Wilcox-Lee and Loria, 1987; McSorley and Duncan, 1995), mulching (Stirling, 1991), and control of other pests such as weeds (Epperson et al., 1982) may also be important in nematode management. In a field experiment, the use of transplants and mulches greatly improved growth and yield of susceptible vegetable crops, even though the population density of *Meloidogyne incognita* was not affected (McSorley and Gallaher, 1995). The recognition that cultural practices may improve tolerance to nematodes is not new (Watson, 1945), but to use them consistently we need better knowledge of the precise conditions under which the desired effects will occur.

Soil solarization

Soil solarization uses solar heating beneath clear plastic sheets or mulch to reduce population densities of nematodes and other soilborne plant pathogens (Katan, 1981). Although most often used in hot climates with low rainfall and cloud cover, solarization has been adapted to humid tropical climates, and there are examples of its use with limited success in temperate climates (McGovern and McSorley, 1997). Root-knot nematodes may be more difficult to manage by this method than other species, but many successful examples have been reported (McGovern and McSorley, 1997). One susceptible crop may be grown after solarization, but nematode populations recover if a second susceptible crop is grown (Overman and Jones, 1986), as would be expected with most nematode management methods. Effects of solarization are not limited to nematodes; the process also affects other organisms, both harmful and beneficial, that are sensitive to elevated soil temperatures.

Tillage

Although tillage may have some effect, the relative benefits of minimum vs. conventional tillage for nematode management are unclear (Minton, 1986; McSorley, 1996). There is some evidence that *Xiphinema americanum* may be reduced by plowing in conventional-tillage systems (Smolik et al., 1995), whereas *Pratylenchus* spp. may be greater under conventional than under minimum tillage (McSorley, 1996). As mentioned earlier, clean fallow may be useful for nematode management, but reductions in nematode populations probably result from the absence of host plants rather than from exposure by frequent disking or plowing.

Timing of planting

Damage to some crops can be minimized by planting during seasons when nematodes are less active (Trivedi and Barker, 1986; Weischer, 1994; McSorley and Duncan, 1995). This approach has worked well for wheat, which is well adapted to cool temperatures (Roberts et al., 1981). Various other cultural practices have been attempted for nematode management (Trivedi and Barker, 1986; Duncan, 1991; Nyczepir, 1991; Weischer, 1994; McSorley and Duncan, 1995; McSorley, 1996), but research is needed to determine the conditions under which these practices will be most effective.

Future Directions and Information Needs

For improved levels of nematode management, it may be necessary to use several cultural practices (Roberts, 1993; Noling and Becker, 1994). There are several excellent examples of integrated nematode management (Roberts, 1993; McSorley and Duncan, 1995). Integrated management programs for *Globodera* spp. in northern Europe (Alphey et al., 1988), *Meloidogyne* spp. in California (Roberts, 1993), and *Heterodera glycines* in North Carolina (Schmitt, 1991) have been reviewed recently. In general, however, integrated approaches have been underused in nematology (Roberts, 1993). Additional research also is needed on interactions of nematodes with other pests and management practices (Roberts, 1993), particularly if nematode management is to evolve into integrated pest management.

Many of the methods presented here are effective in reducing nematode populations or improving crop performance and yield (Trivedi and Barker, 1986; McSorley and Duncan, 1995). However, they cannot eradicate nematodes from an infested site, which means that nematode problems can recur, particularly if susceptible crops are grown continuously without any nematode management. Knowledge of methods and principles is an essential starting point for nematode management, but the available knowledge may not be enough to manage nematodes in a specific situation. Detailed, specific information is needed on the dynamics and damage thresholds of the nematodes for all crop cultivars in the system,

on the efficacy of management practices that are feasible for that crop, on the conditions that influence these practices, and on the economics of the proposed alternatives. Obtaining this information base is a formidable task, requiring detailed, applied studies to obtain information that is highly specific for a particular combination of pest and crop in a particular region. Results obtained in one region may not apply elsewhere. Therefore, the countries, states, and regions that are most successful in developing a detailed research base on nematode and crop biology will have a decided advantage in managing their nematode problems. Local testing by informed growers at the farm level will be important in accelerating and optimizing this process.

References

1. Alphey, T.J.W., M.S. Phillips, and D.L. Trudgill. 1988. Integrated control of potato cyst nematodes using small amounts of nematicide and potatoes with partial resistance. Annals of Applied Biology 113:545-552.
2. Barker, K.R. 1991. Rotation and cropping systems for nematode control: The North Carolina experience. Introduction. J. Nematology 23:342-343.
3. Barker, K.R., and J.P. Noe. 1987. Establishing and using threshold population levels. In J.A. Veech and D.W. Dickson (eds). Vistas on Nematology. Society of Nematologists, Hyattsville, Maryland. pp. 75-81.
4. Brodie, B.B., J.M. Good, and C.A. Jaworski. 1970. Population dynamics of plant nematodes in cultivated soil. Effect of summer cover crops in old agricultural land. J. Nematology 2:147-151.
5. Brodie, B.B., K. Evans, and J. Franco. 1993. Nematode parasites of potatoes. In K. Evans, D.L. Trudgill, and J.M. Webster (eds). Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Wallingford, U.K. pp. 87-132.
6. Brown, D.J.F., A. Dalmasso, and D.L. Trudgill. 1993. Nematode pests of soft fruits and vines. In K. Evans, D.L. Trudgill, and J.M. Webster (eds). Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Wallingford, U.K. pp. 427-462.
7. Carpenter, A.S., and S.A. Lewis. 1991. Aggressiveness and reproduction of four *Meloidogyne arenaria* populations on soybean. J. Nematology 23:232-238.
8. Caswell, E.P., J. DeFrank, W.J. Apt, and C.S. Tang. 1991. Influence of nonhost plants on population decline of *Rotylenchulus reniformis*. J. Nematology 23:91-98.
9. Cook, R., and K. Evans. 1987. Resistance and tolerance. In R.H. Brown and B.R. Kerry (eds). Principles and Practice of Nematode Control in Crops. Academic Press, Sydney, Australia. pp. 179-231.
10. Dropkin, V.H. 1969. The necrotic reaction of tomatoes and other hosts to *Meloidogyne*: Reversal by temperature. Phytopathology 59:1632-1637.
11. Duncan, L.W. 1991. Current options for nematode management. Annual Review of Phytopathology 29:469-490.
12. Duncan, L.W., and E. Cohn. 1990. Nematode parasites of citrus. In M. Luc, R.A. Sikora, and J. Bridge (eds). Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. CAB International, Wallingford, U.K. pp. 321-346.
13. Epperson, J.E., C.C. Dowler, R.B. Chalfant, A.W. Johnson, N.C. Glaze, and D.R. Sumner. 1982. Economic results of pest control intensity for a multiple-cropping system. J. Amer. Soc. for Horticultural Sci. 107:624-627.
14. Fassuliotis, G. 1982. Plant resistance to root-knot nematodes. In R.D. Riggs (ed). Nematology in the Southern Region of the United States. Southern Cooperative Series Bull. 276. Arkansas Agric. Exp. Sta., Fayetteville. pp. 33-49.
15. Fassuliotis, G. 1987. Genetic basis of plant resistance to nematodes. In J.A. Veech and D.W. Dickson (eds). Vistas on Nematology. Society of Nematologists, Hyattsville, Maryland. pp. 364-371.
16. Ferguson, J.J., and M. Mesh. 1997. Organic farming practices. In R.N. Gallaher and R. McSorley (eds). Proceedings of the 20th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Special Series SS-AGR-60, Cooperative Extension Service, Univ. of Florida, Gainesville. pp. 47-51.
17. Flint, M.L., and P.A. Roberts. 1988. Using crop diversity to manage pest problems: Some California examples. Amer. J. Alternative Agric. 3:163-167.
18. Good, J.M. 1968. Relation of plant parasitic nematodes to soil management practices. In G.C. Smart, Jr., and V.G. Perry (eds). Tropical Nematology. Univ. of Florida Press, Gainesville. pp. 113-138.
19. Gray, N.F. 1987. Nematophagous fungi with particular reference to their ecology. Biological Reviews 62:245-304.
20. Hackney, R.W., and O.J. Dickerson. 1975. Marigold, castorbean, and chrysanthemum as controls of *Meloidogyne incognita* and *Pratylenchus alleni*. J. Nematology 7:84-90.
21. Huang, J.S. 1985. Mechanisms of resistance to root-knot nematodes. In J.N. Sasser and C.C. Carter (eds). An Advanced Treatise on *Meloidogyne*. Vol. I. North Carolina State Univ. Graphics, Raleigh, NC. pp. 165-174.
22. Jaffee, B.A., A.E. Muldoon, R. Phillips, and M. Mangel. 1990. Rates of spore transmission, mortality, and production of the nematophagous fungus *Hirsutella rhossiliensis*. Phytopathology 80:1083-1088.
23. Johnson, A.W. 1982. Managing nematode populations in crop production. In R.D. Riggs (ed). Nematology in the Southern Region of the United States. Southern Cooperative Series Bull. 276. Arkansas Agric. Exp. Sta., Fayetteville. pp. 193-203.
24. Johnson, A.W., and R.E. Motsinger. 1989. Suitability of small grains as hosts of *Meloidogyne* species. Supplement to J. Nematology 21:650-653.
25. Katan, J. 1981. Solar heating (solarization) of soil for control of soilborne pests. Annual Review of Phytopathology 19:211-236.
26. Kerry, B.R. 1984. Nematophagous fungi and the regulation of nematode

populations in soil. Helminthological Abstracts Series B 53:1-14.
27. Kerry, B.R. 1990. Microbial control of plant-parasitic nematodes. Supplement to J. Nematology 22:621-631.
28. Khan, A.M., S.K. Saxena, and Z.A. Siddiqui. 1971. Effect of *Tagetes erecta* in reducing root infesting nematodes of tomato and okra. Indian Phytopathology 24:166-169.
29. Maas, P.W.T. 1987. Physical methods and quarantine. In R.H. Brown and B.R. Kerry (eds). Principles and Practice of Nematode Control in Crops. Academic Press, Sydney, Australia. pp. 265-291.
30. McGovern, R.J., and R. McSorley. 1997. Physical methods of soil sterilization for disease management including soil solarization. In N.A. Rechcigl and J.E. Rechcigl (eds). Environmentally Safe Approaches to Crop Disease Control. CRC Lewis Publishers, Boca Raton, Florida. pp. 283-313.
31. McSorley, R. 1996. Impact of crop management practices on soil nematode populations. Soil and Crop Sci. Soc. of Florida Proceedings 55:63-66.
32. McSorley, R., and D.W. Dickson. 1995. Effects of tropical rotation crops on *Meloidogyne incognita* and other plant-parasitic nematodes. Supplement to J. Nematology 27:535-544.
33. McSorley, R., and L.W. Duncan. 1995. Economic thresholds and nematode management. Advances in Plant Pathology 11:147-170.
34 McSorley, R., and R.N. Gallaher. 1992. Managing plant-parasitic nematodes in crop sequences. Soil and Crop Sci. Soc. of Florida Proceedings 51:42-45.
35. McSorley, R., and R.N. Gallaher. 1995. Cultural practices improve crop tolerance to nematodes. Nematropica 25:53-60.
36. McSorley, R., and M.S. Phillips. 1993. Modeling population dynamics and yield losses and their use in nematode management. In K. Evans, D.L. Trudgill and J.M. Webster (eds). Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Wallingford, U.K. pp. 61-85.
37. McSorley, R., D.W. Dickson, J.A. de Brito, and R.C. Hochmuth. 1994. Tropical rotation crops influence nematode densities and vegetable yields. J. Nematology 26:308-314.
38. Minton, N.A. 1986. Impact of conservation tillage on nematode populations. J. Nematology 18:135-140.
39. Muller, R., and P.S. Gooch. 1982. Organic amendments in nematode control. An examination of the literature. Nematropica 12:319-326.
40. Noe, J.P. 1988. Theory and practice of the cropping systems approach to reducing nematode problems in the Tropics. J. Nematology 20:204-213.
41. Noe, J.P., J.N. Sasser, and J.L. Imbriani. 1991. Maximizing the potential of cropping systems for nematode management. J. Nematology 23:353-361.
42. Noling, J.W., and J.O. Becker. 1994. The challenge of research and extension to define and implement alternatives to methyl bromide. Supplement to J. Nematology 26:573-586.
43. Nusbaum, C.J., and H. Ferris. 1973. The role of cropping systems in nematode population management. Annual Review of Phytopathology 11:423-440.
44. Nyczepir, A.P. 1991. Nematode management strategies in stone fruits in the United States. J. Nematology 23:334-341.
45. Opperman, C.H., J.R. Rich, and R.A. Dunn. 1988. Reproduction of three root-knot nematodes on winter small grain crops. Plant Disease 72:869-871.
46. Overman, A.J., and J.P. Jones. 1986. Soil solarization, reaction, and fumigant effects on double-cropped tomato under full-bed mulch. Proceedings of the Florida State Horticultural Soc. 99:315-318.
47. Reddy, K.C., A.R. Soffes, G.M. Prine, and R.A. Dunn. 1986. Tropical legumes for green manure. II. Nematode populations and their effects on succeeding crop yields. Agronomy J. 78:5-10.
48. Rhoades, H.L. 1980. Relative susceptibility of *Tagetes patula* and *Aeschynomene americana* to plant nematodes in Florida. Nematropica 10:116-120.
49. Rhoades, H.L. 1983. Effects of cover crops and fallowing on populations of *Belonolaimus longicaudatus* and *Meloidogyne incognita* and subsequent crop yields. Nematropica 13:9-16.
50. Rickard, D.A., and A.W. Dupree, Jr. 1978. The effectiveness of ten kinds of marigolds and five other treatments for control of four *Meloidogyne* spp. J. Nematology 10:296-297.
51. Riggs, R.D., and T.L. Niblack. 1993. Nematode pests of oilseed crops and grain legumes. In K. Evans, D.L. Trudgill, and J.M. Webster (eds). Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Wallingford, U.K. pp. 209-258.
52. Rivoal, R., and R. Cook. 1993. Nematode pests of cereals. In K. Evans, D.L. Trudgill, and J.M. Webster (eds). Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Wallingford, U.K. pp. 259-303.
53. Roberts, P.A. 1982. Plant resistance in nematode pest management. J. Nematology 14:24-33.
54. Roberts, P.A. 1992. Current status of the availability, development, and use of host plant resistance to nematodes. J. Nematology 24:213-227.
55. Roberts, P.A. 1993. The future of nematology: Integration of new and improved management strategies. J. Nematology 25:383-394.
56. Roberts, P.A., S.D. VanGundy, and H.E. McKinney. 1981. Effect of soil temperature and planting date of wheat on *Meloidogyne incognita* reproduction, soil populations, and grain yield. J. Nematology 13:338-345.
57. Rodriguez-Kabana, R. 1986. Organic and inorganic nitrogen amendments to soil as nematode suppressants. J. Nematology 18:129-135.
58. Rodriguez-Kabana, R. 1992. Cropping systems for the management of phytonematodes. In F.J. Gommers and P.W.T. Maas (eds). Nematology from Molecule to Ecosystem. European Society of Nematologists, Invergowrie, Dundee, U.K. pp. 219-233.
59. Rodriguez-Kabana, R., and G. Morgan-Jones. 1988. Potential for nematode control by mycofloras endemic in the Tropics. J. Nematology 20:191-203.

60. Rodriguez-Kabana, R., P.S. King, D.G. Robertson, and C.F. Weaver. 1988. Potential of crops uncommon to Alabama for management of root-knot and soybean cyst nematodes. Supplement to J. Nematology 20:116-120.
61. Rodriguez-Kabana, R., D.G. Robertson, L. Wells, P.S. King, and C.F. Weaver. 1989. Crops uncommon to Alabama for the management of *Meloidogyne arenaria* in peanut. Supplement to J. Nematology 21:712-716.
62. Sasser, J.N., and D.W. Freckman. 1988. A world perspective on nematology: The role of the Society. In J.A. Veech and D.W. Dickson (eds). Vistas on Nematology. Society of Nematologists, Hyattsville, Maryland. pp. 7-14.
63. Sasser, J.N., and M.F. Kirby. 1979. Crop Cultivars Resistant to Root-knot Nematodes, *Meloidogyne* Species. Department of Plant Pathology, North Carolina State Univ., Raleigh, NC.
64. Schmitt, D.P. 1991. Management of *Heterodera glycines* by cropping and cultural practices. J. Nematology 23:348-352.
65. Schmitt, D.R., and K.R. Barker. 1988. Incidence of plant-parasitic nematodes in the coastal plain of North Carolina. Plant Disease 72:107-110.
66. Seinhorst, J.W. 1970. Dynamics of populations of plant parasitic nematodes. Annual Review of Phytopathology 8:131-156.
67. Small, R.W. 1987. A review of the prey of predatory soil nematodes. Pedobiologia 30:179-206.
68. Smiley, R.W. 1996. Diseases of wheat and barley in conservation cropping systems of the semiarid Pacific Northwest. Amer. J. Alternative Agric. 11:95-103.
69. Smolik, J.D., T.L. Dobbs, and D.H. Rickerl. 1995. The relative sustainability of alternative, conventional, and reduced-till farming systems. Amer. J. Alternative Agric. 10:25-35.
70. Stirling, G.R. 1991. Biological Control of Plant Parasitic Nematodes. CAB International, Wallingford, U.K.
71. Taylor, A.L., and J.N. Sasser. 1978. Biology, Identification and Control of Root-knot Nematodes (*Meloidogyne* Species). North Carolina State Univ. Graphics, Raleigh, NC.
72. Tedford, E.C., B.A. Jaffee, A.E. Muldoon, C.E. Anderson, and B.B. Westerdahl. 1993. Parasitism of *Heterodera schachtii* and *Meloidogyne javanica* by *Hirsutella rhossiliensis* in microplots over two growing seasons. J. Nematology 25:427-433.
73. Trivedi, P.C., and K.R. Barker. 1986. Management of nematodes by cultural practices. Nematropica 16:213-236.
74. Trudgill, D.L. 1991. Resistance to and tolerance of plant parasitic nematodes in plants. Annual Review of Phytopathology 29:167-192.
75. Vandermeer, J.H. 1990. Intercropping. In C.R. Carroll, J.H. Vandermeer, and P.M. Rosset (eds). Agroecology. McGraw-Hill Publishing Co., New York, N.Y. pp. 481-516.
76. Walter, D.E., H.W. Hunt, and E.T. Elliot. 1988. Guilds or functional groups? An analysis of predatory arthropods from a shortgrass steppe soil. Pedobiologia 31:247-260.
77. Watson, J.R. 1921. Control of root-knot, II. Bull. 159. Agric. Exp. Sta., Univ. of Florida, Gainesville.
78. Watson, J.R. 1945. Mulches to control root-knot. Proceedings of the Florida Academy of Sci. 7:151-153.
79. Weischer, B.A. 1994. Where to go in phytonematode control? Phytoparasitica 22:95-99.
80. Wilcox-Lee, D., and R. Loria. 1987. Effects of nematode parasitism on plant-water relations. In J.A. Veech and D.W. Dickson (eds). Vistas on Nematology. Society of Nematologists, Hyattsville, Maryland. pp. 260-266.

REPORT PROFILES PROFITABLE ALTERNATIVE FARMING PRACTICES

Innovative and successful farmers around the country are "switching from conventional pest management practices, which are heavily reliant on pesticides, to profitable alternative agricultural practices that substantially reduce pesticide use," concludes a report published recently by the Natural Resources Defense Council (NRDC).

The report, "Fields of Change: A New Crop of American Farmers Find Alternatives to Pesticides," profiles 22 farmers who produce fruits, vegetables, grains, cotton, and dairy in 16 states: California, Florida, Georgia, Illinois, Iowa, Louisiana, Michigan, Mississippi, Missouri, Montana, New York, North Carolina, Texas, Vermont, Washington, and Wisconsin.

"All of the farmers made the conversion from conventional pest management systems to alternative pest management systems while maintaining, and in many cases improving, the profitability of their operations," the report concludes. The farmers now use alternative techniques such as scouting and monitoring for pest and natural enemy population levels; using precision pesticide application equipment; rotating crops and planting cover crops; switching to biologically-based pest control products; and using conservation tillage, irrigation management, and soil-building.

The report makes five policy recommendations that would facilitate the widespread adoption of alternative pest management practices: implement an education and technical assistance program; increase investment in sustainable and organic farming systems research and extension programs; salvage the Administration's Integrated Pest Management initiative; increase availability of technical and financial cost-share assistance and incentive programs; and define terms and create rewards in the marketplace for foods grown using alternative pest management methods.

"Fields of Change" is $14 plus $3 shipping from NRDC, Publications Department, 40 West 20th St., New York, N.Y. 10011; (212) 727-4486.

Impact of agricultural management on nitrate concentrations in drainage waters

Walter A. Goidstein, Michael J. Scully, Daniel H. Kohl, and Georgia Shearer

Abstract. *Nitrate contamination of surface water resulting from inputs of agricultural drainage water is a widespread problem. To learn whether alternative agricultural practices might ameliorate this problem, we measured NO_3^- in water draining from three neighboring fields from 1970 to 1992. Drainage water from two fields fertilized with N exclusively as composted and liquid manure had NO_3^- concentrations less than 2 ppm (20% of the Public Health Service recommended limit for drinking water). When these fields were converted to a corn/soybean rotation fertilized with anhydrous ammonia, NO_3^- concentration increased about 7- to 10-fold. On a third field, corn was always fertilized with anhydrous ammonia. Changing this field from a rotation of corn, oats and hay to corn/soybean and increasing the rate of N fertilization by about 18% almost doubled the NO_3^- concentration in the drainage water. The corn/soybean rotation most prevalent in the Corn Belt today resulted in high NO_3^- concentrations in the drainage water, while the alternative system prevented NO_3^- problems.*

Key words: nitrate pollution, composted manure, mineral N fertilization, crop rotation

Nitrate contamination of surface water is a widespread problem, and agriculture is probably the largest contributor (Hallberg and Keeney, 1993). The NO_3^- – N concentration in agricultural drainage water often exceeds the U. S. Public Health Service recommended limit of 10 mg/l (National Research Council, 1989). Possible sources of NO_3^- in agricultural drainage water include inorganic N fertilizer (applied to corn [*Zea mays* L.] throughout the Corn Belt), animal manure (especially from point sources like feedlots), and mineralization of soil organic matter.

An important factor contributing to the NO_3^- problem is that inexpensive commercial N fertilizers have made continuous row cropping profitable, and row cropping increases the mineralization of NO_3^- from organic matter (Hallberg and Keeney, 1993). On the other hand, NO_3^- leaching is generally very low under meadow and hay crops (Hallberg et al., 1986; Hallberg and Keeney, 1993), and crops like alfalfa (*Medicago sativa* L.) may even remove previously accumulated NO_3^- (Olson, 1985).

Inorganic N fertilizer is a major source of NO_3^- pollution. For example, a review of several agronomic trials showed that NO_3^- content of drainage water and the total loss of N through drainage both have a close, if not linear, correlation with the application rate of N fertilizer (Baker and Laflen, 1983).

Several strategies have been identified for decreasing NO_3^- concentrations in agricultural drainage water. However, if environmentally advantageous alternatives entail large decreases in crop productivity and farm income, then the cost of lowering NO_3^- concentrations might be too high. The evidence to date, though, suggests that organic farms can be as profitable and productive as conventional farms. An economic study of the productivity and profitability of organic crop/livestock farms in the Midwest from 1974 to 1978 showed that their yields and profits were similar to those of their conventional neighbors (Lockeretz et al., 1981). Similar conclusions regarding productivity of organic farming were drawn by study teams from the U.S. Dept. of Agriculture (1980) and the National Research Council (1989). Therefore, if alternative management reduces NO_3^- contamination, it can be part of a practical and economically feasible solution to the NO_3^- problem.

In this paper, we report a comparison of NO_3^- concentrations in water draining from fields under two management practices. More importantly, this study allowed examination of how NO_3^- concentration in drainage water changed when management changed from application of composted manure in a rotation of corn, oats

W.A. Goldstein is Research Director, Michael Fields Agricultural Institute, W2493 County Road ES, East Troy, WI 53120; M.J. Scully is a retired farmer, 1420 Wiggins, Springfield, IL 62704; D.H. Kohl is Professor and G. Shearer is Research Professor, Emerita, Department of Biology, Washington University, St. Louis, MO 63130. Corresponding author is D.H. Kohl (kohl@biodec.wustl.edu).

(*Avena sativa* L.) and hay to application of anhydrous ammonia in a corn/soybean (*Glycine max* Merr.) rotation. These results were collected in two periods encompassing 23 years (1970-79 and 1989-92).

Materials and Methods

We compared NO_3^- concentrations in drainage water from three fields, designated the West, North and East Fields. From 1970 through 1979, N was applied to the North and East Fields only as composted or liquid manure, while anhydrous ammonia was applied to corn on the West Field (Koepf, 1973). The crop rotation on all three fields was two or three years of corn, followed by oats, then one or two years of hay. From 1989 to 1992, all three fields were cropped exclusively to row crops (corn and soybeans) and fertilized with anhydrous ammonia. These fields are located on Michael Scully's Cockleburr Farm near Buffalo in Sangamon County, central Illinois. They require tile drainage, as do almost all agricultural fields in the area. The subterranean tile lines discharge water into drainage ditches. We collected the effluent from wells sunk into the tile lines at the edge of each of the three fields. The tile lines consist of 10- and 15-cm diameter clay pipes set at a depth of about 90 cm. Each pipe is 30 cm long, and individual pipes are butted against each other. The slope of the tile lines is 8 cm per 100 m. Based on original maps showing the tile lines in the three fields and the opinion of Steffanie Bradely (USDA-Natural Resource Conservation Service Technician for Sangamon County), it is reasonable to assume that each tile line drained only the specific field under which it was located. However, about 15% of the tile under the East Field lay in an area planted to an unfertilized mix of 50% black spruce (*Picea mariana*), 40% douglas fir (*Pseudotsuga menziesii*), and 10% scotch pine (*Pinaceae sylvestris*). Therefore, there may have been a small contribution of water of lower NO3- concentration to the tile effluent from this field.

The soil types found in the drainage areas around the three tiles were determined from soil cores by Charles Love (Soil Scientist, USDA-NRCS, Major Land Resource Area Office, Springfield, Illinois) to belong to the Ipava-Tama-Sable association. These are nearly level or depressional soils formed in loess covered till plains. Soil samples were collected from an area within 17 m on either side of the tile lines, as this is the area that drains directly into them. Particle size and soil organic matter (Walkley and Black, 1934) and total N (Kjeldahl) were analyzed by the University of Wisconsin Soil Testing Laboratory. Wet aggregate stability (Kemper, 1965) was analyzed at Michael Fields Agricultural Institute. The soil properties of the three fields were qualitatively similar (Table 1), the most important differences being the higher organic matter and aggregate stability on the North Field compared with the West Field or East Field. There is no reason to believe that the small differences in soil properties between fields could have led to the large differences in NO_3^- concentration in drainage water described below. Furthermore, differences in soil properties between fields would not have affected the quality of drainage water from a single field after management was changed.

Table 1. Properties of soil draining into three tiles sampled in July, 1994 (mean and SE, %).

	West Field (n=13)	North Field (n=15)	East Field (n=4)
Sand	16.1 (0.2)	15.8 (0.1)	15.5 (0.5)
Silt	63.3 (0.7)	61.8 (0.6)	60.5 (0.5)
Clay	20.6 (0.7)	22.5 (0.6)	24.0 (0.0)
Organic matter	3.58 (0.10)	4.29 (0.14)	3.33 (0.34)
Nitrogen	0.17 (0.01)	0.20 (0.01)	0.18 (0.01)
Aggregate stability	37.7 (1.8)	48.3 (1.6)	44.8 (3.5)
Soil type[1]			
Tama	44.3	0	0
Ipava	22.4	66.6	50
Sable	33.3	33.3	50

[1] Tama soils (2% slope) are well drained; Ipava soils (2% slope) are less well drained; Sable soils (1% slope) are poorly drained.

The North Field (about 12 ha) and the East Field (about 7 ha) were farmed from 1970 to 1984 using an alternative system described previously (Scully, 1981). The entire farm was 160 ha, and was a mixed crop/livestock operation from which about 100 cattle, 350 fattened hogs and 68 metric tons (t) of oats were sold each year. About 75 t of a mixture of soybean meal and minerals were purchased annually. Crops were fertilized with composted and liquid manure from the animals on the farm. On the North Field, first-year corn received no N fertilization, second-year corn typically was fertilized with 22 t/ha of composted manure, and third-year corn with 11 to 22 t/ha of composted manure, supplemented with liquid manure (4 to 8 m^3/ha). However, the latter was low in N (about 0.02%). On the East Field, corn was typically fertilized with composted manure at 5.5 t/ha. Chicken manure (13 t/ha) was applied to sorghum (*Sorgum vulgare*) in 1971. No N was applied to other crops, except a very small amount (2 kg/ha) applied as liquid manure to hay on the North Field in 1972. Biodynamic herbal preparations or the biodynamic Pfeiffer starter were added to the compost and liquid manure. The biodynamic fermented manure and sprays were applied to the soil and crops, respectively, from 1977 to 1984. In accordance with recommendations of Brookside Soil Testing Laboratory (New Knoxville, Ohio), soils were fertilized with rock phosphate, lime, and muriate of potash. The North Field was fertilized with rock phosphate at 0.6 t/ha and lime at 1.1 t/ha in 1971, and muriate of potash at 0.2 t/ha in 1975 and 1979. The East Field was fertilized with rock phosphate at 0.6 t/ha in 1972, lime at 1.1 t/ha in 1972, and muriate of potash at 168 kg/ha in 1971. From 1970 to 1980, no commercial N fertilizers were used. When corn followed corn in the rotation from 1970 to 1984, insecticides were used against corn rootworm if necessary (about half the time). From 1980 to 1984, herbicides were banded in the row for second- and third-year corn at half the recommended rate. The West Field (about 28 ha) was farmed by a neighbor

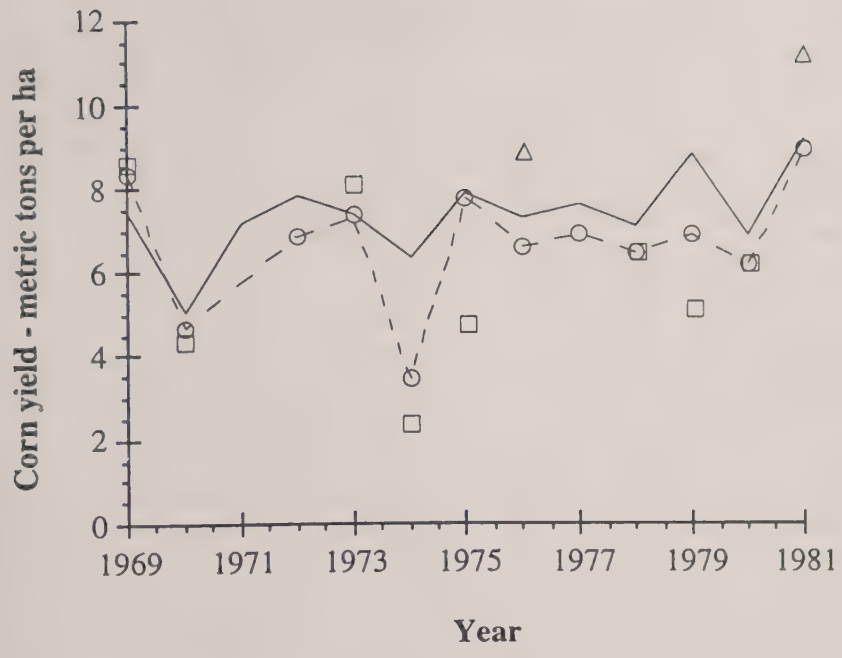


Figure 1. Sangamon County average corn yields and corn yields on Cockleburr Farm. Solid lines connect data for county average yields (supplied by the Illinois Agricultural Statistics Service, Springfield). Circles are average corn yields for all the fields on Cockleburr Farm managed by Scully as described in Materials and Methods. Squares are yields of corn grown on the North Field from 1969 to 1979 (data for later years not available). Triangles are yields of corn grown on the North Field in 1976 and 1981, the only years in which corn was grown on this field before the change in management.

who applied anhydrous ammonia on all corn crops.

Rotations on all fields from 1969 through 1984 included closely planted crops, unlike the corn/soybean rotation typical of this part of the Corn Belt. However, these rotations were comparable to conventional practice on mixed grain/livestock farms in other parts of the Corn Belt such as Iowa and Minnesota (Klepper et al., 1977). These rotations included one, two, or three years of corn grown for grain, or sudan grass (*Sorgum sudanense*) grown for silage, followed by oats underseeded with an alfalfa/red clover (*Trifolium pratense*)/grass mixture. This mixture was hayed for one or two years and then plowed under before corn or sudan grass was planted again. In 1971, sorghum was substituted for corn on the East Field.

Corn yields for the North and East Fields are available from 1969 to 1981, but not after that. No corn yield data are available for the West Field. Figure 1 shows corn yields for the North and East Fields, and average corn yields for all fields managed by Scully, in comparison to average corn yields for Sangamon County. From 1969 to 1981, average corn yield for the entire farm (excluding the West Field) was 6.7 t/ha (91% of the county average for the same years). On the East Field, the average corn yield during the same period (only two years) was 10 t/ha (136% of the county average for those two years). The average corn yield on the North Field was 5.8 t/ha (78% of the county average for same years). The lower average yield on the North Field was largely influenced by the low yield in a single year (1974), when heavy and frequent rainfall prevented effective cultivation for weed control (M. Scully, contemporaneous field notes). The rotations, nutrient applications, and corn yields on the North and East Fields were similar to those on the organic farms studied by Lockeretz et al. (1981), which on average were competitive with conventional farms in productivity and profitability.

Beginning in 1985, the entire farm was leased to a conventional farmer who placed the West and North Fields in a corn/soybean rotation with application of N as anhydrous ammonia at somewhat higher rates than were previously applied to the West Field. The East Field was continued in hay until 1989, when it, too, was placed in a corn/soybean rotation and fertilized with anhydrous ammonia. Crop rotations and the amount and form of N applied to each field are given in Table 2. Information on anhydrous ammonia applications was provided by the farmers who applied it. On the North and East Fields, N was applied as composted manure from 1969 to 1984 and as anhydrous ammonia from 1985 to 1992. N analyses (Kjeldahl) of composted manure were available for 1963-71 (Biochemical Research Laboratory, Spring Valley, New York) and for 1973 and 1975 (Brookside Soil Testing Laboratory, New Knoxville, Ohio). We used the average value for these years (0.75% N) to calculate N applications from composted manure in other years. N in liquid manure was analyzed by Biochemical Research Laboratory in 1963 and 1969, and by Brookside Soil Testing Laboratory in 1972 and 1975. We used the average value of 0.026% N to calculate N applications from liquid manure in other years.

Except when the tile lines were not running, water samples were taken from tile discharge wells for NO_3^- analysis approximately weekly from 1970 until early 1975, and biweekly after that until 1979. From 1970 to early 1975, samples for the initial study were taken and analyzed by the method of Wood et al. (1967) under the supervision of F. Sollo at the Illinois State Water Survey (Urbana). From 1975 to 1979, samples were analyzed by D.H. Kohl and G. Shearer at Washington University by the method of Bremner and Keeney (1965). Samples from 1989 to 1992 were taken by W. Becker (Central Illinois Agricultural Research Farms) and M. Scully, and sent to the Plant and Soil Testing Laboratory, University of Wisconsin, Madison, for analysis by the method of Wood et al. (1967). Although different laboratories, using different methods, analyzed the samples over the 23-year study, field-to-field comparisons in any given year were based on measurements made by a single laboratory, using a single method.

Statistical comparisons were by student

Table 2. Crop rotation, and total amount of N and form of N fertilizer applied to fields on Cockleburr Farm, 1969 to 1992.

	West Field			North Field			East Field		
		Nitrogen			Nitrogen			Nitrogen	
Year	Crop	kg/ha	Form[1]	Crop	kg/ha	Form	Crop	kg/ha	Form
1969	hay[2]	0		corn	90	M[1]	hay	0	
1970	corn	167	AA[1]	corn	74	M	sudan grass	0	
1971	corn	188	AA	oats	0		sorghum	125	M
1972	oats		0	hay	2	M	oats	0	
1973	hay	0		corn	0		hay	0	
1974	corn	167	AA	corn	168	M	hay	0	
1975	corn	209	AA	corn	139	M	sudan grass	0	
1976	corn	167	AA	oats	0		corn	84	M
1977	oats	0		hay	0		oats	0	
1978	hay	0		corn	0		hay	0	
1979	corn	167	AA	corn	168	M	hay	0	
1980	corn	NA		corn	173	M	sudan grass	0	
1981	corn	NA		oats	0		corn	84	M
1982	oats	NA		hay	0		oats	0	
1983	hay	NA		corn	0		hay	0	
1984	corn	NA		corn	168	M	hay	0	
Change in Management									
1985	corn	202	AA	corn	202	AA	hay	0	
1986	soybean	0		soybean	0		hay	0	
1987	corn	202	AA	corn	202	AA	hay	0	
1988	soybean	0		soybean	0		hay	0	
1989	corn	202	AA	corn	202	AA	corn	112	AA
1990	corn	202	AA	soybean	0		corn	202	AA
1991	soybean	0		corn	202	AA	soybean	0	
1992	corn	202	AA	soybean	0		corn	202	AA

[1] AA = anhydrous ammonia; M = manure.
[2] Hay was always a mixture of alfalfa/red clover/grass.

t-test (two-tailed) using annual average NO_3^- concentrations.

Results and Discussion

Results from the entire study are shown in Fig. 2. The data from 1970 to 1979 confirmed preliminary results from the project (Koepf, 1973). The size of the variation in NO_3^- concentration results primarily from seasonal variation. Tile effluents were collected from all three fields at the same time. Although this variation is larger in water from the West Field than the North and East Fields, the coefficient of variation is similar among the three fields. The NO_3^- concentrations in water draining from the North and East Fields (which received N only as composted manure) were remarkably low, similar to those found under forest, unfertilized pastures, meadows, and grasslands (Hallberg et al., 1986). On the other hand, NO_3^- concentrations in water draining the West Field often exceeded the U.S. Public Health Service recommended limit for drinking water (10 mg NO_3^- – N/l). Such levels are not unusual for fertilized cropland (Kohl et al., 1971; Hallberg et al., 1986). Although the crop rotations employed on the North and West Fields were almost identical (two or three years of corn, followed by one year of oats, and one year of hay), differences between the two fields in NO_3^- concentration were statistically significant ($p<0.0001$) every year tested and over the entire period (mean ± standard error of 1.5 ± 0.05 and 9.3 ± 1.0 mg/l, respectively), indicating that the difference was caused by the difference between the two fields in N fertilization, either the amount or the form (composted manure vs. anhydrous ammonia).

The temporal pattern of NO_3^- concentration in water draining the West Field appeared to follow the rotation, with a lag of about one year. NO_3^- concentration dropped after oats and hay, reaching its lowest point by the first year of corn, after which it climbed again with increasing years of corn. Even when NO_3^- concentration in water from the West Field was at its lowest (in the year following hay), it still was much higher than water from the North and East Fields, which had received N only as composted manure.

During this period (1970 to 1979), NO_3^- concentration differed little between the North and East Fields, even though more than twice as much composted manure was applied to the North Field. From 1970 through 1979, row crops were grown on the North Field in six of the ten years, whereas row crops were grown on the East Field in only two of the ten years. On the alternatively managed North and East Fields, NO_3^- concentration was not clearly related to either the crop rotation or how much composted manure was applied. Uptake of N by corn on the North Field may have compensated for the extra composted manure applied, although N uptake by

corn on the West Field did not compensate for the anhydrous ammonia application. It also is possible that the high C and N content of composted manure promoted denitrification, and the high C/N ratio of the composted manure may have promoted immobilization of NO_3^-. All these factors would decrease the amount of NO_3^- available for leaching.

The most striking feature of the data is the large increase in NO_3^- concentration of water from the North and East Fields after the change in management to the conventionally fertilized, corn/soybean rotation. The mean NO_3^- – N concentration increased 7.3-fold (to 10.2 mg/l) in the North Field and 10.7-fold (to 17.1 mg/l) in the East Field. These increases were highly significant ($p<0.0001$). After the change to conventional practice with a corn/soybean rotation, NO_3^- concentration in the East Field was 1.7-times higher than in the North Field (Fig. 2), even though this change in management occurred in 1985 on the North Field but not until 1989 on the East Field, which had been planted to hay without N fertilization for the previous six years. It is possible that NO_3^- concentration was higher in the East than the West Field from 1990 to 1992 because of N accumulation by hay grown the previous six years on the East Field. This seems unlikely, however, since the hay was harvested each year. Also, the heavier application of composted manure to the North Field before 1985, by promoting immobilization of NO_3^-, may have continued to cause more of the inorganic N applied after 1985 to be retained. This hypothesis is supported by the fact that the NO_3^- level in the North Field was gradually climbing by the end of the monitoring period, approaching the level in other fields. This increase may indicate that the residual effect of the previous manuring in reducing available N was gradually decreasing.

The change in management also affected NO_3^- concentration in the West Field, which had received anhydrous ammonia during the entire study. When the West Field was changed from a rotation that included both row crops (corn) and closely planted crops (oats and hay) to one that had row crops only (corn and

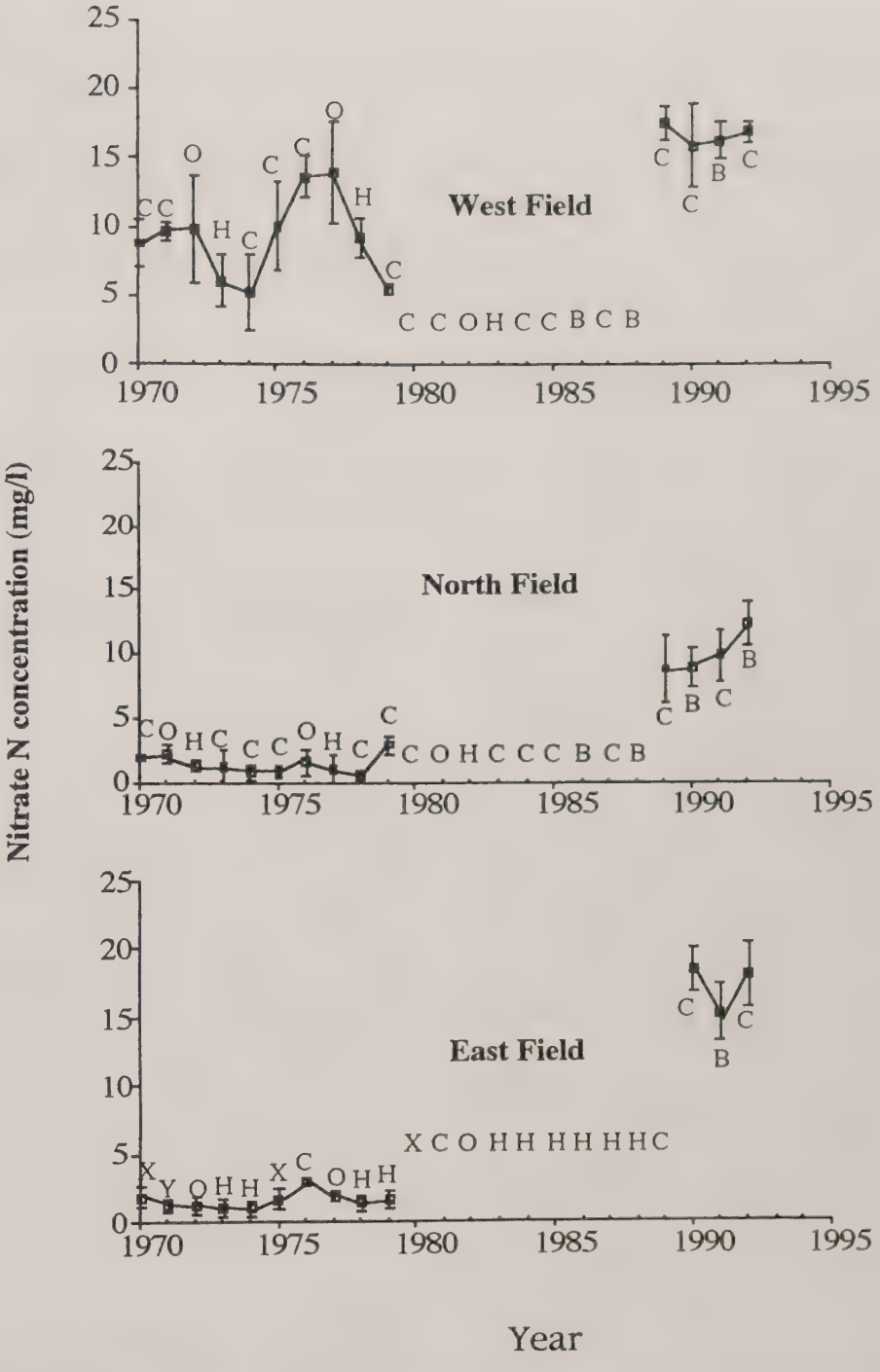


Figure 2. Annual mean NO_3^- – N concentrations in tile effluents from three fields from 1970 to 1979 and from 1989 to 1992. The upper panel shows NO_3^- – N concentration in water draining from the West Field; the lower two panels show NO_3^- –N concentration in water draining from the North and East Fields. Error bars represent ±1 SD around the mean. The crop planted in the indicated year is indicated by letter: C = corn; B = soybeans; O = oats; H = hay; X = sudan grass; Y = sorghum. No water samples were collected between 1980 and 1989.

soybeans) and somewhat higher applications of ammonia fertilizer, NO_3^- concentration nearly doubled. During the earlier period, the only time that NO_3^- levels approached those found after the change in management was after corn had been grown three years in a row (1974 to 1976) The average annual rate of N fertilizer applied as ammonia was 107 kg/ha over the ten years 1970-79 (with N fertilizer being applied in six of ten years), increasing to 126 kg/ha over the eight years 1985-92 (with N fertilizer being applied in five of eight years). This 18% increase undoubtedly contributed to the increase in NO_3^- concentration. However, the change from a rotation that included oats and hay to a corn/soybean rotation may also have contributed. The decline in NO_3^- concentration in water draining from the West Field following oats and hay during the period 1970-79 did not occur following soybeans (no fertilizer applied) in the later corn/soybean rotation.

Management practices that are potential candidates for influencing NO_3^- concentrations in the drainage water from these fields include the total amount of N applied to each field, the form of the applied N, and the relative frequency of closely grown and row crops in the rotation. The data presented here do not allow us to evaluate how much each of these factors contributed to the observed results. Nevertheless, the results show that the corn/soybean system that is most widespread in the central Corn Belt is highly conducive to NO_3^- pollution of tile water, while the alternative system employed by Scully prevented the problem. This result underlines the fruitfulness of doing long-term research to evaluate complex systems that integrate several measures that reduce NO_3^- pollution, such as those employed in the alternative system used here.

Acknowledgments. We thank F. Sollo of the Illinois Water Survey, William Becker of Central Illinois Agricultural Research Farms, and the Soil and Plant Testing Laboratory, University of Wisconsin, Madison, for gathering and testing samples, and Charles Love and Steffanie Bradely, USDA-NRCS, for inspecting soils around tile lines. We also thank three anonymous reviewers for their thoughtful and helpful comments.

References

1. Baker, J.L., and J.M. Laflen. 1983. Water quality consequences of conservation tillage. J. Soil and Water Conservation 38:186-193.
2. Bremner, J.M., and D.R. Keeney. 1965. Steam distillation techniques for determination of ammonium, nitrite and nitrate. Analytical Chemistry 32:485-495.
3. Hallberg, G.R., and D.R. Keeney. 1993. Nitrate. In W.M. Alley (ed). Regional Ground-Water Quality. Van Nostrand Reinhold, New York, N.Y. pp. 297-322.
4. Hallberg, G.R., J.L. Baker, and G.W. Randall. 1986. Utility of tile effluent studies to evaluate the impact of agricultural practices on groundwater. In Agricultural Impacts on Groundwater. National Well Water Association, Worthington, Ohio. pp. 298-326.
5. Kemper, W.D. 1965. Aggregate stability. In C.A. Black, D.D. Evans, L.E. Ensminger, J.L. White, F.E. Clark, and R.C. Dinauer (eds). Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. Soil Sci. Soc. Amer, Madison, Wisconsin. pp. 499-510.
6. Klepper, R., W. Lockeretz, B. Commoner, M. Gertler, S. Fast, D. O'Leary, and R. Blobaum. 1977. Economic performance and energy intensiveness on organic and conventional farms in the corn belt: A preliminary comparison. Amer. J. Agric. Economics 59:1-12.
7. Koepf, H.H. 1973. Organic management reduces leaching of nitrate. Biodynamics 108:20-29.
8. Kohl, D.H., G.B. Shearer, and B. Commoner. 1971. Fertilizer nitrogen: Contribution to nitrate in surface water in a corn belt watershed. Science 174:1331-1333.
9. Lockeretz, W., G. Shearer, and D.H. Kohl. 1981. Organic farming in the corn belt. Science 211:540-547.
10. National Research Council. 1989. Alternative Agriculture. Board on Agriculture. National Academy Press, Washington, D.C.
11. Olson, R.A. 1985. Nitrogen problems. In Plant Nutrient Use and the Environment. The Fertilizer Institute, Washington D.C. pp. 115-138,
12. Scully, M. 1981. Cockleburr farm. Biodynamics 137:13-19.
13. U.S. Dept. of Agriculture. 1980. Report and Recommendations on Organic Farming. Study Team on Organic Farming. U.S. Government Printing Office, Washington D.C.
14. Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.
15. Wood, E.D., S.A.J. Armstrong, and F.A. Richards. 1967. Determination of nitrate in sea-water by cadmium-copper reduction to nitrite. J. Marine Biological Assoc. of the United Kingdom 47:13-31.

POULTRY PRODUCERS TRY TO DEVELOP VOLUNTARY CLEANUP PLAN

Poultry producers across the country are trying to develop a voluntary plan to manage the waste from their operations in an attempt to avoid either federal or state-by-state regulations, according to *The New York Times*. The EPA and USDA are working on a broad strategy for reducing runoff from livestock and poultry operations; a final report is expected in November. Some states, including Maryland, have been addressing problems associated with nutrient runoff from chicken manure with their own regulations.

Groups such as the National Broiler Council, National Turkey Federation, and the United States Poultry and Egg Association have been discussing for several months how to change their waste runoff management to better protect water and soil quality. But participants at a recent meeting could not agree on a plan. "They are still grappling with questions about who will pay for research into new technologies and educational programs, as well as new nutrient management plans geared more for controlling phosphorous runoff, as opposed to current plans that focus on nitrogen," according to the article.

Assessment of legume and nonlegume ground covers on Coleoptera: Coccinellidae density for low-input pecan management

Natasha R. Rice, Michael W. Smith, Raymond D. Eikenbary, Don Arnold, W. Louis Tedders, Bruce Wood, B. Scott Landgraf, Glenn G. Taylor, and Gordon E. Barlow

Abstract. *An annual legume cover crop was evaluated in pecan orchards to increase coccinellids that would reduce pecan aphids. Treatments were a 'Dixie' crimson clover and hairy vetch mixture and a grass sod. Coccinellids were abundant on the legume ground covers, but coccinellid density in the tree canopy was rarely affected by ground cover treatment. There were substantial differences between the coccinellid species collected from the legumes and from the trees. In Oklahoma,* Olla v-nigrum *(Mulsant) and* Cycloneda munda *(Say) were the main species in the trees, while* Hippodamia convergens *Guerin,* Coccinella septempunctata *L., and* Coleomegilla maculata lengi *Timberlake were dominant species in the legumes. In Georgia,* Harmonia axyridis *(Pallas) was the dominant species in the trees, and* C. septempunctata *in the legumes. Pecan aphids at two Oklahoma sites usually were not affected by cover crop treatment, but at the Georgia site, early-season aphids frequently were lower with a legume cover crop than with a grass sod. The accumulated effect of all aphid predators and parasitoids attracted to the legume aphids may have reduced the density of the pecan aphid.*

Key words: aphid, Aphididae, beneficial arthropods, pecan, Coccinellidae, Fabaceae, ground cover

Intensive agricultural management practices emphasizing chemical use have created certain economic, environmental and social problems that have led to the development of alternative management systems. Legumes or mixtures of legumes can be grown as ground covers in pecan (*Carya illinoinensis* [Wangenheim] K. Koch) orchards and may offer certain advantages over perennial grass sod, such as supplying N (White et al., 1981; Wood et al., 1983; Smith et al., 1996b) and increasing beneficial arthropods that may control certain pecan pests (Bugg et al., 1991b). Legumes were once commonly used in pecan orchards as cover or green manure crops before widespread availability of inexpensive synthetic N fertilizers in the 1940s and 1950s (Allison, 1957; White et al., 1981; Tedders, 1983; Allison and Ott, 1987; Ott, 1987). Today the common sod in pecan orchards is bermudagrass (*Cynodon dactylon* [L.] Pers.), but it competes for moisture and nutrients, and thus decreases tree growth and yield (Gossard and Hammar, 1957; Ware and Johnson, 1958).

Pecan growers use intense pest control programs with eight to ten insecticide applications in the southeastern U.S. and five to seven in the south central U.S. (Tedders, 1983; Bugg et al., 1991b). Pests of major concern include: pecan nut casebearer (*Acrobasis nuxvorella* Neunzig, Lepidoptera: Pyralidae); hickory shuckworm (*Cydia caryana* (Fitch); Lepidoptera: Tortricidae), pecan weevil (*Curculio caryae* (Horn), Coleoptera: Curculionidae); and aphids (Homoptera: Aphididae). Other pests that occasionally are a problem include: phylloxera (*Phylloxera notabilis* Pergande, *P. russelae* Stoetzal, and *P. devastatrix* Pergande, Homoptera: Phylloxeridae); fall webworm (*Hyphantria cunea* (Drury), Lepidoptera: Arctiidae); and walnut datana (*Datana integerrima* G. and R., Lepidoptera: Notodontidae). The frequent use of certain insecticides has led to pesticide resistance in aphids (Dutcher and Htay, 1985), outbreaks of secondary pests (Ball, 1981; Mizell, 1991), and reductions

Approved for publication by the Director of the Oklahoma Agricultural Experiment Station.

Natasha R. Rice is a graduate student and Michael W. Smith is Professor, Department of Horticulture and Landscape Architecture, Oklahoma State University, Stillwater, OK 74078; Raymond D. Eikenbary is Professor and Don Arnold is Survey Entomologist, Department of Entomology, Oklahoma State University, Stillwater, OK 74078; W. Louis Tedders is Entomologist and Bruce Wood is Horticulturist, USDA-ARS Southeastern Fruit and Tree Nut Research Laboratory, Byron, GA 31008; B. Scott Landgraf is Soil Scientist and Glenn G. Taylor and Gordon E. Barlow are Horticulturists, Noble Foundation, Ardmore, OK 73402. Corresponding author is M.W. Smith: mws@okway.okstate.edu.

in beneficial arthropod populations that act as a natural control of pecan pests (Dutcher, 1983; Dutcher and Payne, 1983; Tedders, 1983; Mizell, 1991).

A complex of three aphid species attack pecan: the blackmargined aphid (*Monellia caryella* [Fitch]); the yellow pecan aphid (*Monelliopsis pecanis* Bissell); and the black pecan aphid, (*Melanocallis caryaefoliae* [Davis]) (Homoptera: Aphididae) (Tedders, 1978, 1983; Tedders et al., 1982). Blackmargined aphids and yellow pecan aphids, commonly called the yellow aphid complex, are the most common foliar-feeding aphids on pecans (Tedders, 1978; Payne et al., 1979), and are a limiting factor in pecan production (Neel et al., 1985). These aphids reduce pecan production by clogging the phloem, inducing chlorosis, and suppressing photosynthesis in pecan leaves (Wood and Tedders, 1982; Wood et al., 1985, 1988), thus depleting carbohydrate reserves (Wood and Tedders, 1982), and reducing nut size, weight and yield (Tedders and Wood, 1985). When pecan aphid densities are below recommended threshold levels, few adverse effects on net photosynthesis have been observed (Wood and Tedders, 1986).

The yellow aphid complex is attacked by predators and parasitoids (Shepard, 1973; Tedders, 1978; Flores, 1981; Edelson, 1982; Watterson and Stone, 1982; Liao et al., 1984, 1985; Edelson and Estes, 1987). Cool season cover crops such as hairy vetch (*Vicia villosa* Roth) and crimson clover (*Trifolium incarnatum* L.) might be used in the understory of pecan trees to provide alternative prey such as aphids and thrips that are not themselves pests of pecans, but that ensure retention of lady beetles and other predators until pecan aphids become available in early May (Tedders, 1983; Bugg et al., 1990, 1991a). The alternative prey aphids common on crimson clover and hairy vetch are blue alfalfa aphid (*Acyrthosiphon kondoi* Shimji), pea aphid (*Acyrthosiphon pisum* (Harris)), and cowpea aphid (*Aphis craccivora* Koch) (Bugg et al., 1990; Smith et al., 1994). Bugg et al. (1990) found that blue alfalfa and pea aphids were abundant on crimson clover beginning in February through the end of March, with hairy vetch sustaining abundant aphids from April through the first part of May.

Bugg et al. (1991b) proposed a cover crop management system for pecans to enhance beneficial arthropods in the orchard. Several cool-season and warm-season cover crops and crapemyrtle (*Lagerstroemia indica* L.) have been evaluated for increasing aphidophagous insects and other entomophaga to enhance biological control in vegetable and pecan agroecosystems (Wood et al., 1983; Mizell and Schiffhauer, 1987; Bugg and Dutcher, 1989, 1993; Bugg and Ellis, 1990; Bugg et al., 1990, 1991a; Smith et al., 1994). These studies show that certain cover crops could provide a seasonal sequence of foods to beneficial arthropods that might otherwise disperse from pecan orchards.

Two types of pecan orchards are common in the pecan industry, native orchards or groves, and cultivar orchards. Cultivar orchards are composed of at least two cultivars (for pollination). The cultivars are asexually propagated (grafted onto selected rootstocks), so that trees of the same cultivar are genetically identical. Trees are planted in the geometric configurations common for all orchards. Native orchards are developed from wild stands of timber where pecan is the dominant species. Species other than pecan are removed, then pecan trees are thinned to achieve the recommended tree density. Therefore, trees in a native orchard occur at random. Trees are removed continually to avoid crowding in native orchards. Native orchards are less likely to experience major problems with disease or epidemic outbreaks of certain pests because each tree is genetically unique. Production potential of a cultivar orchard is usually greater than that of a native orchard, and the market value of the nuts from cultivars is normally greater because of the higher kernel yield and more uniform appearance compared with native pecans.

We used three criteria in choosing a ground cover to evaluate for pecan orchards. First, the ground cover should harbor large densities of prey aphids to attract beneficial arthropods. Second, the ground cover should be a cool-season type to avoid substantial competition with the trees for moisture during the dry summer months; this was particularly important for native orchards, since few are irrigated. Third, the ground cover should be a legume that can supply N for pecan production. Profit margins for native pecan orchards are smaller than for cultivar orchards, so a priority was to get the dual benefit of increased beneficials that might reduce foliage damage by aphids, and the elimination of commercial N inputs. In this study we chose a mixture of 'Dixie' crimson clover and hairy vetch as the ground cover to evaluate for arthropod management. The suitability of this mixture as an N source is discussed by Smith et al. (1996b).

Materials and Methods

Orchard sites

The study was conducted at three sites: Knight Creek Farm, a commercial native pecan orchard in central Oklahoma near Sapulpa; the Noble Foundation Research Ranch native pecan orchard in southern Oklahoma near Burneyville; and the USDA-ARS Southeastern Fruit and Tree Nut Research Laboratory cultivar orchard ('Desirable', 'Stuart', 'Cape Fear' and 'Cheyenne' cultivars) at Byron, Georgia. Tree density (trees/ha) was 36 at Sapulpa, 25 at Burneyville, and 49 at Byron.

Legume establishment and management

Preparation for planting the ground cover consisted of applying glyphosate in August 1991 to kill existing vegetation. The soil was tilled about 2.5 cm deep each year then planted at the following times: September 1991, 1992 and 1993 at Sapulpa; October 1991, September 1992, and September 1993 at Burneyville; and October 1991, 1992, and 1993 at Byron. Hairy vetch and 'Dixie' crimson clover seed were inoculated with the appropriate *Rhizobium* then broadcast at 8 kg/ha and 10 kg/ha, respectively. The soil then was packed with a roller. At Sapulpa and Burneyville the entire 5 ha legume plot was planted in clover and vetch; at Byron the row middles were alternated between clover and vetch. P and K were applied as required, based on soil test results. At all sites, 5 ha of bermudagrass was left intact as the control plot. The legume and control plots were separated by 0.5 km at Sapulpa,

1.5 km at Burneyville, and 0.1 km at Byron.

Plots with grass ground covers were mowed five times during the growing season at all sites. The clover/vetch ground covers were mowed once when the hairy vetch began to senesce, and residues were left on the surface until the area was lightly tilled in September for replanting. Trees at Burneyville were not irrigated, but irrigation was used at Sapulpa (sprinkler) and Byron (trickle).

Pest control

In 1992 and 1994 at Sapulpa, *Bacillus thuringiensis* var. *kurstaki* was applied during June against first generation pecan nut casebearer. In 1993 at Sapulpa, chlorpyrifos was applied on April 21 and May 3 against phylloxera, and on June 7 against pecan nut casebearer. Carbaryl was applied to control pecan weevil at Sapulpa on September 15 and October 1, 1992, August 28 and September 15, 1993, and August 10 and September 12, 1994. At Burneyville, chlorpyrifos was sprayed on April 16,1992, against phylloxera, and *Bacillus thuringiensis* var. *kurstaki* was applied on June 4, 1992 and June 7, 1994, for control of pecan nut casebearer. Carbaryl was applied for control of pecan weevil on August 23 and September 8, 1992. At Burneyville, carbaryl was applied for control of pecan weevil on September 1 and September 17, 1992, and on September 5 and September 25, 1994. At Byron, no insecticides were used during the study.

Insect sampling

Lady beetle adults (*Hippodamia convergens* Guerin, *Coccinella septempunctata* L., *Coleomegilla maculata lengi* Timberlake, *Cycloneda munda* (Say), *Olla v-nigrum* (Mulsant), *Harmonia axyridis* (Pallas), *Anatis* sp., Coleoptera: Coccinellidae) were sampled on legumes at 7- to 10-day intervals, April through June, using a 38-cm diameter sweep net. Each replication consisted of ten sweeps collected between 10 A.M. and 2 P.M. Samples were bagged, transported to the laboratory, and frozen for later identification and counting. We did not monitor lady beetles in the grass ground cover; however, observations and occasional sampling found few lady beetles.

We sampled lady beetle adults in the tree canopy at 7- to 10-day intervals from May until October using a vacuum sampling device (D-Vac Co., Ventura, CA). We took care to position the collection device below the limb before the limb was disturbed to avoid having lady beetles escape collection. Five 0.1-m^2 areas were sampled per tree (replication) in the legume and the grass plots between 10 A.M. and 2 P.M. Samples were deposited into plastic bags, transported to the laboratory, frozen, and later identified and counted. Aphids (*Monelliopsis pecanis, Monellia caryella* and *Melanocallis caryaefoliae*) were counted on ten compound leaves per tree (replication) at 7- to 10-day intervals. Tree canopy samples and aphid counts were at a height of 3 to 4 m.

Experimental design and analysis

Treatments were replicated five times at each site. We analyzed the data as a completely randomized design by date and site, using analysis of variance with Fisher's F-test. We used $p<.05$ as the significance level for differences between treatment means.

Results and Discussion

Lady beetle densities

Densities of adult lady beetles in the tree canopy were not affected by ground cover at Sapulpa and Burneyville on any sampling date during the three-year study. At Byron there was a significant difference between ground cover treatments once during the three years. Therefore, data were pooled over ground cover type (Figs. 1-3).

Lady beetles were occasionally abundant on the legumes at each site (Figs. 1-3). Density on the legumes at Sapulpa and Burneyville peaked during early to mid-May each year. At Byron there was an increase in lady beetle density on vetch late in May 1992, but during the other two years it remained nearly constant until the legumes senesced. During 1993 and 1994 there were similar densities of lady beetles on the clover and vetch at Byron, but in 1992 vetch had more lady beetles than the clover.

Few lady beetles were collected from the tree canopy at Sapulpa in 1992 and 1993 (Fig. 1), suggesting that there was little migration from the legumes to the tree canopy. In 1994, lady beetle densities in the tree canopy were highly variable. Pecan aphid density generally was low during all three years at Sapulpa (Table 1). Therefore, any lady beetles that migrated to the trees would soon leave the orchard in search of food.

At Burneyville there appeared to be an increase in lady beetles in the tree canopies, either coinciding with peak density of lady beetles in legumes or immediately after the peak (Fig. 2). However, densities in tree canopies were not affected by ground cover type. This suggests that during mid-May to early June, lady beetles scatter widely, exploring available habitat in search of food. If suitable prey was not available, they quickly left the area.

At Byron, results were similar to those at Sapulpa and Burneyville in that there was an increase in lady beetles in the tree canopies during early June, followed by a decline (Fig. 3). However, at Byron there also were large increases in lady beetles collected from the tree canopies during the latter part of the growing season each year. Ground cover was unlikely to affect the late season lady beetles, since the legumes had senesced by June and were replaced by vegetation similar to that in the nonlegume treatment. Pecan aphids during the late summer and fall were more abundant at Byron than at the two sites in Oklahoma (Tables 1-3). Perhaps the availability of food attracted lady beetles to the trees during the later part of the growing season. The only significant difference in lady beetle density in canopies was in late April 1993 at Byron. Trees with a legume ground cover had 8 lady beetles per m^2 of canopy compared to none using a nonlegume ground cover.

We observed a substantially different distribution of lady beetle species in the pecan canopy compared to the legumes (Figs. 4 and 5). Also, the species distribution was different between Oklahoma and Georgia. In Oklahoma, the main species sampled in the pecan canopy were *O. v-nigrum* and *C. munda*. The main species in the legumes were *H. convergens, C. septempunctata* and *C. maculata lengi*. In Georgia, *H. axyridis* was the main species in the trees, and *C. septempunctata* was the

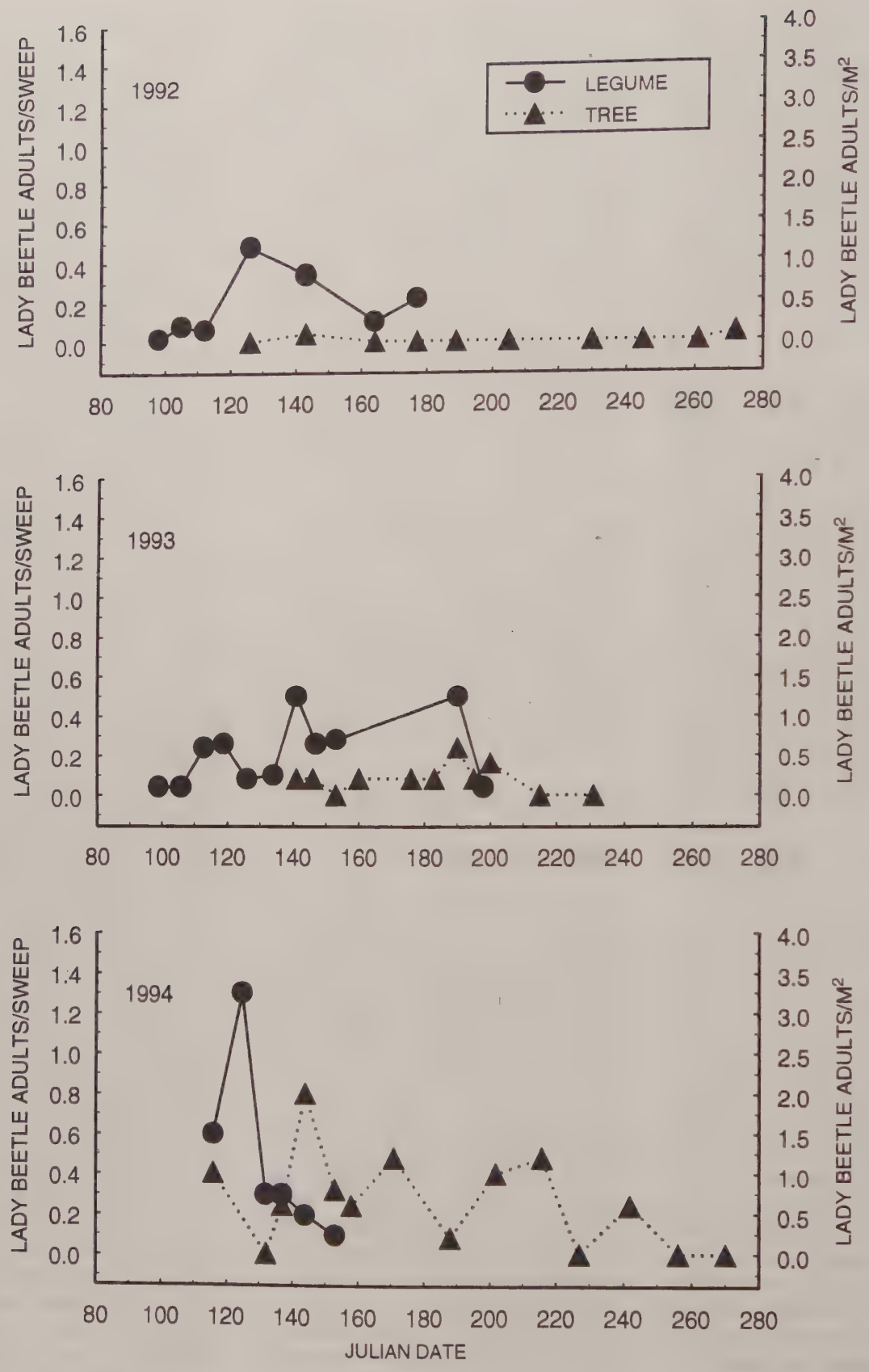


Fig. 1. Adult lady beetle density on legumes and in the tree canopy at Sapulpa, Oklahoma, 1992-94. Data are pooled over ground cover treatment.

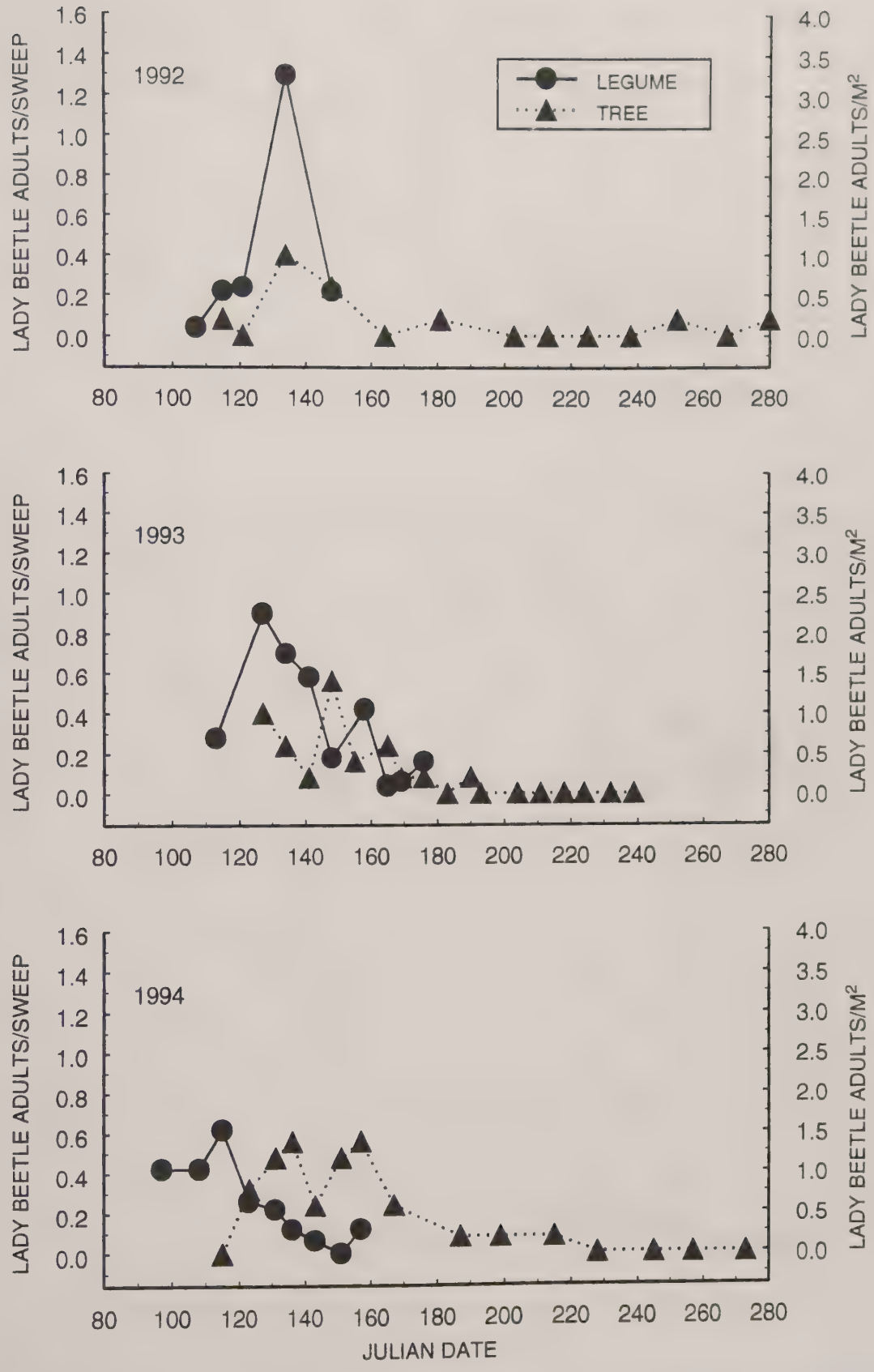


Fig. 2. Adult lady beetle density on legumes and in the tree canopy at Burneyville, Oklahoma, 1992-94. Data are pooled over ground cover treatment.

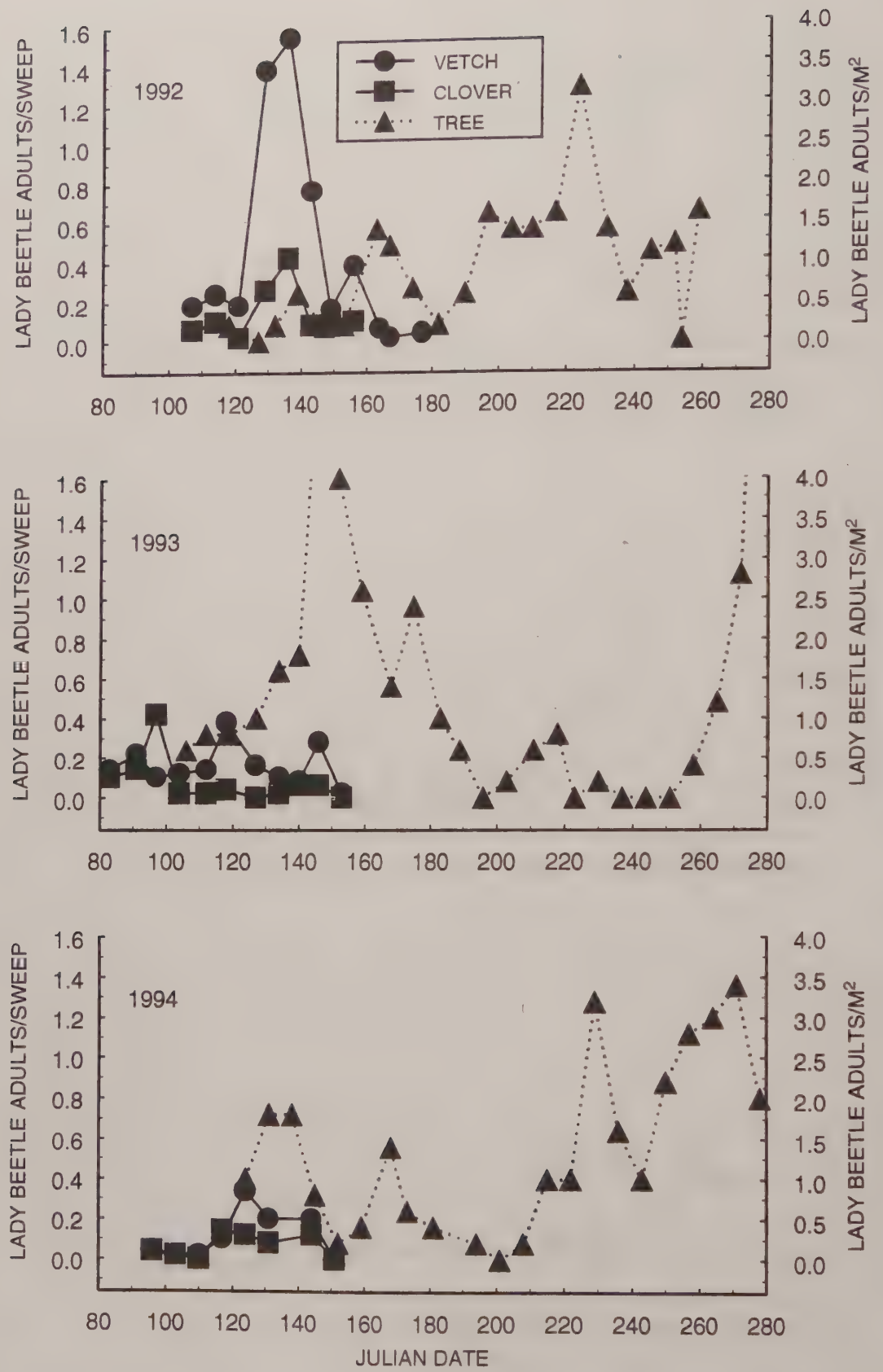


Fig. 3. Adult lady beetle density on legumes and in the tree canopy at Byron, Georgia, 1992-94. Data are pooled over ground cover treatment.

Table 1. The influence of ground cover on the number of aphids (yellow aphid complex) per compound leaf, Sapulpa, Oklahoma.

	Aphids/leaf			Aphids/leaf			Aphids/leaf	
1992	Legume	Grass	1993	Legume	Grass	1994	Legume	Grass
May 5	0.1	0.1	May 20	0.7	1.2	Apr 26	0	0
May 22	0.1	0.1	Jun 1	1.0	0.3	May 12	0.1	0
Jun 12	0.2	0.1	Jun 8	1.1	0.3	May 17	0	0
Jun 25	0.3*	0	Jun 24	1.0	1.8	May 24	0	0
Jul 7	0	0	Jul 1	2.0	3.9	Jun 2	0	0
Jul 15	0.1	0.1	Jul 8	1.2	0.4	Jun 7	0	0
Jul 23	0.1	0	Jul 13	0.5*	0	Jun 20	0	0
Jul 30	0.1	0	Jul 15	0.1	0.1	Jul 7	0.1	0.1
Aug 17	0.1	0	Jul 21	0	0	Jul 21	0.1	0.1
Sep 1	1.5	0.4	Aug 3	0	0	Aug 4	0.1	0.1
Sep 17	21.5*	5.3	Aug 10	0	0	Aug 15	0.1	0.1
Sep 28	49.1	17.5	Aug 18	0	0	Aug 30	0.1	0.1
						Sep 13	0.1	0.1
						Sep 27	0.1	0.1

*Significantly different within date ($p<.05$).

Table 2. The influence of ground cover on the number of aphids (yellow aphid complex) per compound leaf, Burneyville, Oklahoma

	Aphids/leaf			Aphids/leaf			Aphids/leaf	
1992	Legume	Grass	1993	Legume	Grass	1994	Legume	Grass
Apr 24	0.3	0.1	May 7	0.2*	1.1	Apr 25	0	0
Apr 30	0.2	0.2	May 14	0	0.4	May 3	0	0
May 13	17.0*	72.0	May 21	2.3	1.3	May 11	0	0
May 27	0.1	0.1	May 28	294.4*	5.6	May 16	0.1	0
Jun 11	0.1*	0.9	Jun 4	0.8	0.7	May 23	0	0
Jun 29	0	0.1	Jun 18	0.3	0.1	May 31	0	0.1
Jul 17	0	0.1	Jun 25	0.1	0.1	Jun 6	0.1	0.1
Jul 21	0	0	Jul 2	0.1	0.1	Jun 16	0.1	0.1
Jul 31	0.1	0.1	Jul 9	0.1	0.1	Jul 6	0.1	0.1
Aug 12	0.1	0	Jul 12	0.1	0.1	Jul 18	0.1	0.1
Aug 25	0.2*	0	Jul 23	0	0	Aug 3	0.1	0.1
Sep 8	22.0*	0.2	Jul 30	0.1	0	Aug 16	0.1	0.1
Sep 23	3.0*	43.9	Aug 6	0.1	0	Sep 2	0	0
Oct 9	7.2	6.8	Aug 12	0.2	0	Sep 14	0	0
			Aug 27	0.2	0.1	Sep 30	0	0
			Sep 9	0.3	1.5			

*Significantly different within date ($p<.05$).

main species in the legumes. This suggests that many of the species observed on the legumes are unlikely to migrate to the trees in large numbers when the legume aphids are depleted.

Aphid density

We observed no black aphids at the two Oklahoma sites, and very few at Byron, except in 1993. At Byron in 1993, black aphids peaked on September 23, with 62 aphids per compound leaf. There were no significant differences between treatments, except on October 6, when trees with grass ground covers had 52 black aphids per leaf, compared with 3 per leaf for trees with legume ground covers.

There were few significant differences in the number of yellow aphids (yellow aphid complex) per compound leaf at Sapulpa and Burneyville during the three years (Tables 1 and 2). Sometimes there were more aphids on the trees with legume ground covers, but at other times the trees with a grass ground cover had more. Low aphid densities at these two sites may have contributed to the lack of clear results concerning the effect of ground cover on pecan aphids. At Byron there generally were more pecan aphids than at the other two sites. While the legumes were present in the spring, the differences in pecan aphid densities that were significant suggested that beneficials associated with the legumes reduced the number of pecan aphids.

Discussion

Two of the lady beetle species collected in this study were introduced to the U.S.: *C. septempunctata* and *H. axyridis* (Angalet and Jacques, 1975; Cartwright et al., 1979; Schaefer et al., 1987; Chapin and Brou, 1991; Kidd et al., 1995). *C. septempunctata* was first released in Oklahoma

Table 3. The influence of ground cover on the number of aphids (yellow aphid complex) per compound leaf, Byron, Georgia.

	Aphids/leaf			Aphids/leaf			Aphids/leaf	
1992	Legume	Grass	1993	Legume	Grass	1994	Legume	Grass
Apr 24	0	0.3	Apr 27	0.2	0.6	May 6	1.2	1.8
May 8	0.7	3.6	May 6	0.8*	2.9	May 11	0.3	0.4
May 14	1.7	3.9	May 12	4.7*	13.4	May 18	0.3	0.2
May 22	3.5	1.7	May 20	2.4*	22.9	May 25	0	0.1
May 28	0.8	0.8	May 24	2.0*	10.7	Jun 1	0	0
Jun 4	0.9	0.3	Jun 2	3.2	4.6	Jun 8	0.1	0
Jun 11	1.0*	0.6	Jun 11	1.2*	2.5	Jun 15	0.1	0
Jun 18	4.0*	1.1	Jun 17	1.0	1.9	Jun 23	0	0.5
Jun 25	2.4	1.3	Jun 24	0.1*	0.5	Jun 29	0.2	0.5
Jul 2	3.0	6.3	Jul 1	0.1	0.6	Jul 13	0.1*	0.9
Jul 8	2.7	4.2	Jul 8	0.1	0.2	Jul 20	0.7*	10.0
Jul 16	9.5	29.6	Jul 15	0	0	Jul 27	4.7*	14.4
Jul 23	12.1	8.9	Jul 22	0	0.2	Aug 3	2.8*	7.2
Jul 31	2.4	5.3	Jul 30	0	0	Aug 10	2.3	2.0
Aug 7	1.4	1.9	Aug 6	0	0	Aug 18	0.7	0.3
Aug 12	0.1*	1.3	Aug 11	0	0	Aug 24	0.1*	0.7
Aug 18	0.*	0.4	Aug 18	0.1	0.2	Aug 31	0	0.5
Aug 26	0.8*	0.4	Aug 25	0	1.3	Sep 7	0.4	0.3
Sep 1	0.4	0.2	Sep 1	0.3	6.6	Sep 14	0.6	0.5
Sep 8	0.1	0.2	Sep 9	10.6*	36.1	Sep 21	0.6	0.8
Sep 14	0.4	0.6	Sep 16	61.6	47.2	Sep 28	0.8	0.8
Sep 23	0.5	1.5	Sep 23	47.8	38.5	Oct 5	0.4	0.6
Sep 30	1.1	1.7	Sep 30	26.4	43.2	Oct 12	0.4	0.3
Oct 9	0.8	2.4	Oct 6	3.5	29.6	Oct 19	0.2	0.4
Oct 14	0.6	1.3	Oct 15	1.1	1.2	Oct 26	0.2	0.6
Oct 22	0.4	1.0	Oct 22	3.0	7.0			

*Significantly different within date ($p<.05$).

in 1975 (Cartwright et al., 1979). It is primarily aphidophagous (Hodek, 1966), and was a dominant species on the legumes at Oklahoma and Georgia. Ipert (1965) reported that *C. septempunctata* preferred plants less than 0.5 m tall. His observation is consistent with our findings, since *C. septempunctata* was one of the principle Coccinellids collected from the legume ground cover, but was infrequently in the tree canopy.

H. axyridis was introduced into California in 1916, with subsequent releases in 1964 and 1965. It was released at several sites on the East Coast from 1978 to 1985 (Gordon, 1985; Chapin and Brou, 1991), with several specimens released between 1978 to 1981 in pecan orchards at Byron (Tedders and Schaefer, 1994). *H. axyridis* was first reported as established in Louisiana and Mississippi in 1988-1990 (Chapin and Brou, 1991), and on the West Coast in 1993 (Dreistadt et al., 1995). Tedders and Schaefer (1994) reported that the first major recovery indicating establishment of *H. axyridis* in Georgia was in 1990. In Georgia, *H. axyridis* was the most abundant coccinellid we collected from the pecan canopy, but made up only a small proportion of the coccinellids collected from the legumes. In Oklahoma, we collected *H. axyridis* from the pecan canopies but not the legumes, confirming its arboreal preference reported earlier (Tedders and Schaefer, 1994). This is the first report of *H. axyridis* collection in Oklahoma. Since this study, *H. axyridis* has been observed frequently in Oklahoma pecan orchards, and it congregates in large masses on light colored buildings for a few days during the fall.

Several coccinellids are primarily aphidophagous, such as *C. septempunctata, H. convergens, Olla,* and *Cycloneda* (Hodek, 1966). The species specialized in aphids are more mobile (that is, likely to disperse when aphids are depleted) than polyphagous species like *C. maculata lengi*, which feed on pollen or aphids (Smith, 1960; Ewert and Chiang, 1966). Habitat preferences vary among coccinellids. *O. v-nigrum*, an arboreal coccinellid, was the most abundant species on pecan, but we found few on the legumes in Oklahoma. In Georgia, *O. v-nigrum* was the third most abundant coccinellid in the pecan canopy. *C. septempunctata* appears to prefer the lower stratum as habitat, consistent with the report by Ipert (1965). Results for *H. convergens* and *C. munda* in Oklahoma suggest that they did not strongly prefer either the terrestrial or arboreal habitat. *H. convergens* has a positive photoresponse and a neutral response to humidity (Hodek, 1973), generally favoring higher strata.

Ground cover type did not substantially affect coccinellid density within the pecan canopy, although coccinellids were abundant on the legumes. This is probably related to the habitat preferences of each coccinellid species; arboreal species rarely visited the legumes, while those preferring the lower stratum were rarely collected from the pecan canopy. Aphid densities in

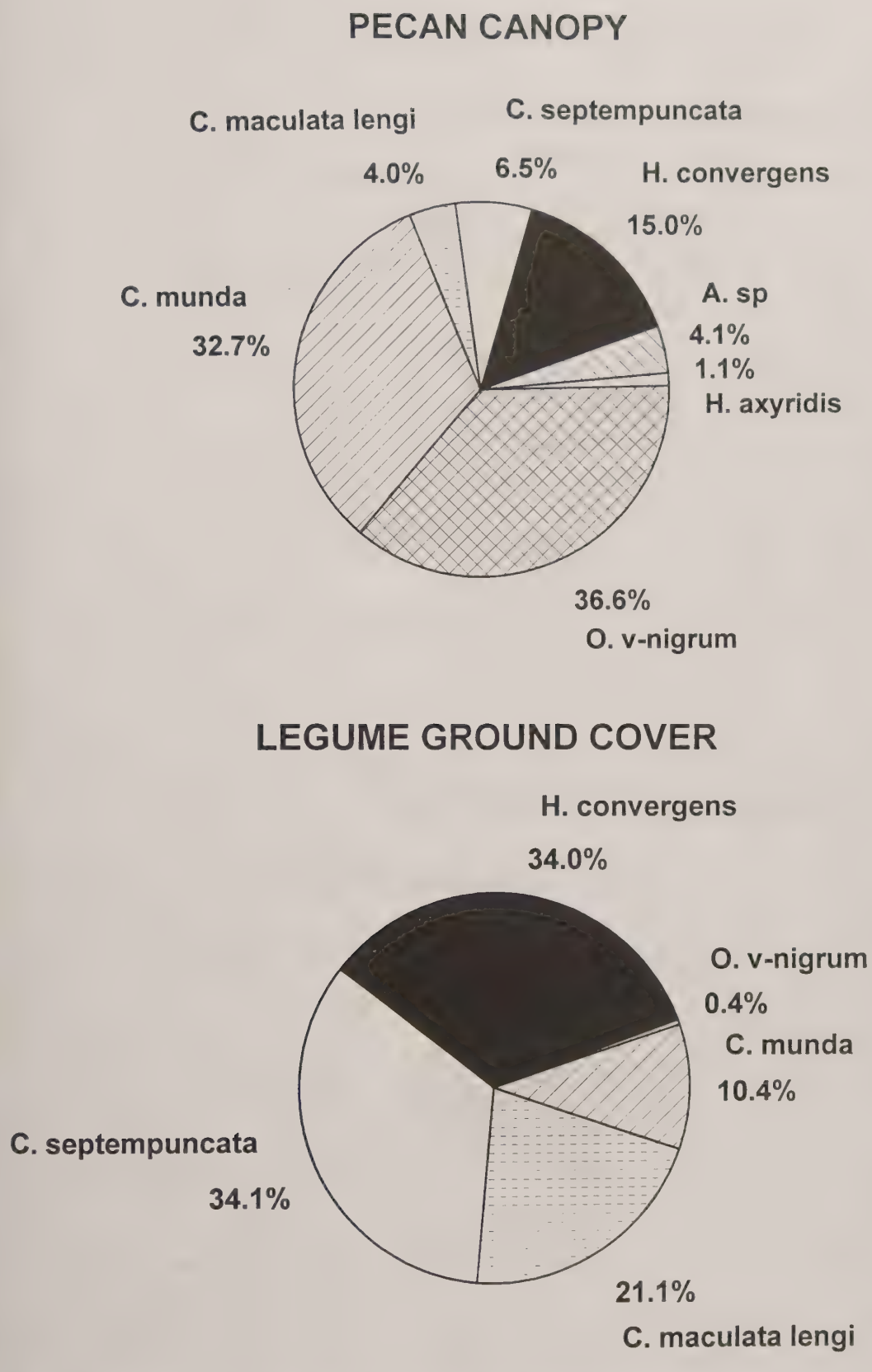


Fig. 4. Adult lady beetle species distribution in the pecan canopy and in the legumes at Oklahoma. Data are pooled over the three years and two sites.

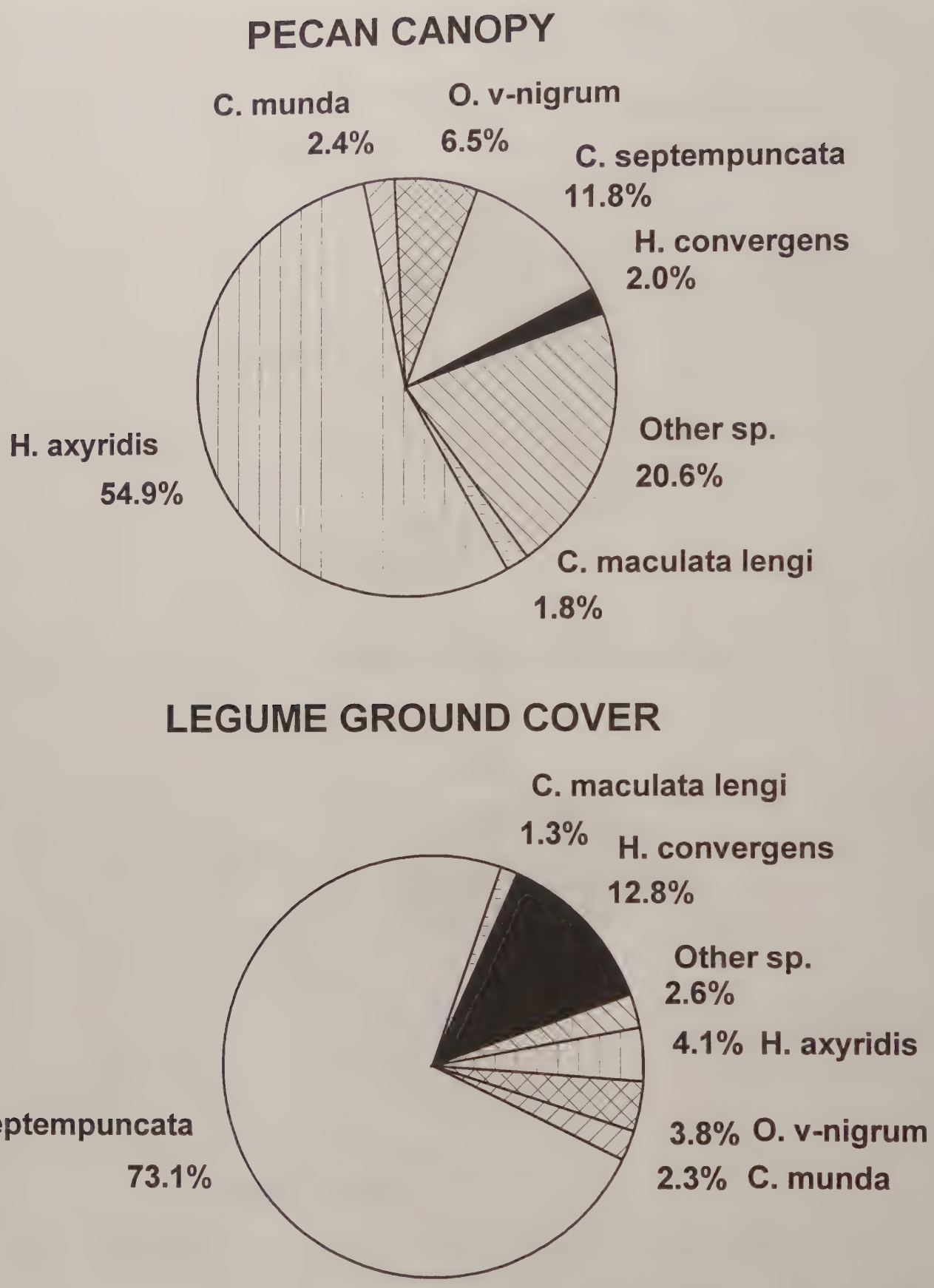


Fig. 5. Adult lady beetle species distribution in the pecan canopy and in the legumes at Georgia. Data are pooled over the three years.

Oklahoma rarely were affected by ground cover type, but in Georgia early-season aphids were generally less abundant with a legume ground cover. However, coccinellid density in the pecan canopy generally was not affected by ground cover. Having fewer aphids in the pecans with legume ground covers may be related to the densities of beneficial arthropods other than coccinellids associated with the legumes (Smith et al., 1996a). Bugg et al. (1990) reported that crimson clover and hairy vetch helped to increase and maintain high densities of coccinellids; however, there was no apparent effect on pecan aphid density. LaRock and Ellington (1996) reported that an integrated management program using improved cultural practices to increase beneficial arthropods, inoculative releases of green lacewing and coccinellids, and reduced pesticide applications were successful for aphid management in a New Mexico pecan orchard.

Legume ground covers that enhance beneficial arthropods in the orchard appear to suppress aphids at certain times. For this control strategy to be effective, pesticide use must be minimized, and whenever possible, selective pesticides should be used. For example, *Bacillus thuringiensis* var. *kurstaki,* or tebufenzide can be used against lepidopteran pests with little effect on nontarget organisms.

Carbaryl currently is the preferred pesticide for pecan weevil, a pest that is normally active from late July through early October. Pecan fruit expands to full size by about mid-August. During this time the ovule expands basepetally from the distal end of the fruit and is filled with a liquid endosperm. While the endosperm is liquid, pecan weevils feed on the fruit, causing it to abort within a few days. Egg laying begins when the fruit reaches the dough stage (the endosperm has developed cell walls, and cotyledonary material is being deposited in the ovule) about late August to early September. Growers in Oklahoma normally delay carbaryl application until the pecans are in the dough stage, and therefore susceptible to egg laying.

In both Georgia and Oklahoma, emergence of pecan weevil from the soil is monitored and insecticide is applied only when an economic threshold is reached. Normally, one to three insecticide applications are required to control pecan weevil. Application of carbaryl or other insecticides labeled for pecan weevil eliminates many beneficial arthropods during the latter part of the growing season, and can cause aphids to increase rapidly. Until an alternative control is developed for pecan weevil no other option is available. However, since this insecticide application occurs late in the growing season, biological control techniques are a suitable option during most of the growing season.

References

1. Allison, F.E. 1957. Nitrogen and soil fertility. In USDA Yearbook of Agriculture. U.S. Govt. Printing Office, Washington, D.C. pp. 85-94.
2. Allison, J.R., and S.L. Ott. 1987. Economics of using legumes as a nitrogen source in conservation tillage systems. In J.F. Power (ed). The Role of Legumes in Conservation Tillage Systems. Soil Conservation Soc. Amer., Ankeny, Iowa. pp. 145-150.
3. Angalet, G.W., and R.L. Jacques. 1975. The establishment of *Coccinella septempunctata* L. in the continental United States. Cooperative Economic Insect Report 25(27):883-884.
4. Ball, J.C. 1981. Pesticide-induced differences in relative abundance of mites on pecans. J. Economic Entomology 74:425-427.
5. Bugg, R.L., and J.D. Dutcher. 1989. Warm-season cover crops for pecan orchards: Horticultural and entomological implications. Biological Agric. and Horticulture 6:123-148.
6. Bugg, R.L., and J.D. Dutcher. 1993. *Sesbania exaltata* (Rafinesque-Schmaltz) Cory (Fabaceae) as a warm-season cover crop in pecan orchards: Effects on aphidophagous Coccinellidae and pecan aphids. Biological Agric. and Horticulture 9:215-229.
7. Bugg, R.L., and R.T. Ellis. 1990. Insects associated with cover crops in Massachusetts. Biological Agric. and Horticulture 7:47-68.
8. Bugg, R.L., S.C. Phatak, and J.D. Dutcher. 1990. Insects associated with cool-season cover crops in southern Georgia: Implications for pest control in truck-farm and pecan agroecosystems. Biological Agric. and Horticulture 7:17-45.
9. Bugg, R.L., J.D. Dutcher, and P.J. McNeil. 1991a. Cool-season cover crops in the pecan orchard understory: Effects on Coccinellidae (Coleoptera) and pecan aphids (Homoptera: Aphididae). Biological Control 1:8-15.
10. Bugg, R.L., M. Sarrantonio, J.D. Dutcher, and S.C. Phatak. 1991b. Understory cover crops in pecan orchards: Possible management systems. Amer. J. Alternative Agric. 6:50-62.
11. Cartwright, B.O., R.D. Eikenbary, G.W. Angalet, and R.K. Campbell. 1979. Release and establishment of *Coccinella septempunctata* in Oklahoma. Environmental Entomology 8:819-823.
12. Chapin, J.B., and V.A. Brou. 1991. *Harmonia axyridis* (Pallas), the third species of the genus to be found in the United States (Coleoptera: Coccinellidae). Proc. Entomological Soc. Washington 93:630-635.
13. Dreistadt, S.H., K.S. Hagen, and L.G. Bezark. 1995. *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), first western United States record for this Asiatic lady beetle. Pan-Pacific Entomologist 71:135-136.
14. Dutcher, J.D. 1983. Carbaryl and aphid resurgence in pecan orchards. J. Georgia Entomological Soc. 18:492-495.
15. Dutcher, J.D., and U.T. Htay. 1985. Resurgence and insecticide resistance problems in pecan aphid management. In W.W. Neel, W.L. Tedders, and J.D. Dutcher (eds). Aphids and Phylloxeras of Pecan. Spec. Pub. 38. Georgia Agric. Exp. Sta., Athens, Georgia. pp. 17-29.
16. Dutcher, J.D., and J.A. Payne. 1983. Impact assessment of carbaryl, dimethoate, and dialifor on foliar and nut pests of pecan orchards. J. Georgia Entomological Soc. 18:495-507.
17. Edelson, J.V. 1982. Seasonal abundance, distribution and factors affecting population dynamics of yellow pecan aphids (*Monellia caryella* and *Monelliopsis nigropunctata*). Ph.D.

thesis. Dept. of Entomology, Auburn Univ., Auburn, Alabama.
18. Edelson, J.V., and P.M. Estes. 1987. Seasonal abundance and distribution of predators and parasites associated with *Monelliopsis pecanis* Bissell and *Monellia caryella* (Fitch)(Homoptera: Aphidae [sic]). J. Entomological Sci. 22:336-347.
19. Ewert, M.A., and H.C. Chiang. 1966. Dispersal of three species of coccinellids in corn fields. Canadian Entomologist 98:999-1001.
20. Flores, R.J.F. 1981. A comparison of field population dynamics in relation to developmental time and fecundity under laboratory conditions of the foliage aphid species complex on pecan. Ph.D. thesis. Dept. of Entomology, Texas A&M Univ., College Station.
21. Gordon, R.D. 1985. The Coleoptera (Coccinellidae) of America north of Mexico. J. New York Entomological Soc. 93:1-912.
22. Gossard, A.C., and H.E. Hammar. 1957. Differential potassium fertilization of pecan trees combined with summer cultivation and sod systems of orchard management. Proc. Southeastern Pecan Growers' Assoc. 50:51-60.
23. Hodek, I. (ed). 1966. Ecology of Aphidophagous Insects. Proc. Symp. Liblice near Prague, 1965. Academia, Prague, and Dr. W. Junk, The Hague.
24. Hodek, I. (ed). 1973. Biology of Coccinellidae. Dr. W. Junk, The Hague, and Academia, Prague.
25. Ipert, G. 1965. Contributions a l'étude de la spécificité chez les principales Coccinelles aphidiphages des Alpes-Maritimes et des Basses-Alpes. Entomophaga 10:159-178.
26. Kidd, K.A, C.A. Nalepa, E.R. Day, and M.G. Waldvogel. 1995. Distribution of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in North Carolina and Virginia. Proc. Entomological Soc. Washington 97:729-731.
27. LaRock, D.R., and J.J. Ellington. 1996. An integrated pest management approach, emphasizing biological control, for pecan aphids. Southwestern Entomologist 21:153-166.
28. Liao, H.T., M.K. Harris, F.E. Gilstrap, D.A. Dean, C.W. Agnew, G.J. Michels, and F. Mansour. 1984. Natural enemies and other factors affecting seasonal abundance of the blackmargined aphid on pecans. Southwestern Entomologist 9:404-420.
29. Liao, H.T., M.K. Harris, F.E. Gilstrap, and F. Mansour. 1985. Impact of natural enemies on the blackmargined pecan aphid, *Monellia caryella* (Homoptera: Aphidae). Environmental Entomology 14:122-126.
30. Mizell, R.F. III. 1991. Pesticides and beneficial insects: Application of current knowledge and future needs. In B.W. Wood and J.A. Payne (eds.). Pecan Husbandry: Challenges and Opportunities. First National Pecan Workshop Proceedings. ARS-96. Agric. Research Service, U.S. Dept. of Agriculture, Springfield, Virginia. pp. 47-54.
31. Mizell, R.F. III, and D.E. Schiffhauer. 1987. Seasonal abundance of the crapemyrtle aphid, *Sarucallis kahawaluokalani*, in relation to the pecan aphids, *Monellia caryella* and *Monelliopsis pecanis* and their common predators. Entomophaga 32:511-520.
32. Neel, W.W., W.L. Tedders, and J.D. Dutcher. 1985. Aphids and phylloxeras of pecan. Spec. Pub. 38. Georgia Agric. Exp. Sta., Athens, Georgia.
33. Ott, S.L. 1987. An economic and energy analysis of crimson clover as a nitrogen fertilizer substitute in grain sorghum production. In J.F. Power (ed). The Role of Legumes in Conservation Tillage Systems. Soil Conservation Soc. Amer., Ankeny, Iowa. pp. 150-151.
34. Payne, J.A., H.L. Malstrom, and G.E. KenKnight. 1979. Insect pests and diseases of the pecan. Reviews and Manuals ARM-S 5. Science and Education Admin., U.S. Dept. of Agriculture, New Orleans, Louisiana.
35. Schaefer, P.W., R.J. Dysart, and H.B. Specht. 1987. North American distribution of *Coccinella septempunctata* (Coleoptera: Coccinellidae) and its mass appearance in coastal Delaware. Environmental Entomology 16:368-373.
36. Shepard, M. 1973. Seasonal incidence and vertical distribution of aphids and beneficial arthropods on pecan trees. Proc. Southeastern Pecan Growers' Assoc. 66:153-159.
37. Smith, B.C. 1960. A technique for rearing coccinellid beetles on dry foods, and influence of various pollens on the development of *Coleomegilla maculata lengi* Timb. (Coleoptera: Coccinellidae). Canadian J. Zoology 38:1047-1049.
38. Smith, M.W., R.D. Eikenbary, D.C. Arnold, B.S. Landgraf, G.G. Taylor, G.E. Barlow, B.L. Carroll, B.S. Cheary, N.R. Rice and R. Knight. 1994. Screening cool-season legume cover crops for pecan orchards. Amer. J. Alternative Agric. 9:127-134.
39. Smith, M.W., D.C. Arnold, R.D. Eikenbary, N.R. Rice, A. Shiferaw, B.S. Cheary, and B.L. Carroll. 1996a. Influence of ground cover on beneficial arthropods in pecan. Biological Control 6:164-176.
40. Smith, M.W., A. Shiferaw, and N.R. Rice. 1996b. Legume ground covers as a nitrogen source in pecan. J. Plant Nutrition 19:1111-1124.
41. Tedders, W.L. 1978. Important biological and morphological characteristics of the foliar-feeding aphids of pecans. Tech. Bull. 1579. Agric. Research Service, U.S. Dept. of Agriculture, Washington, D.C.
42. Tedders, W.L. 1983. Insect management in deciduous orchard ecosystems: Habitat manipulation. Environmental Management 7:29-34.
43. Tedders, W.L., and P.W. Schaefer. 1994. Release and establishment of *Harmonia axyridis* (Coleoptera: Coccinellidae) in the southeastern United States. Entomological News 105:228-243.
44. Tedders, W.L., and B.W. Wood. 1985. Estimates of the influence of feeding by *Moneliopsis pecanis* and *Monellia caryella* on the fruit foliage carbohydrate reserves, and tree productivity of mature "Stuart" pecans. J. Economic Entomology 78:642-646.
45. Tedders, W.L., B.W. Wood, and J.W. Snow. 1982. Effects of feeding by *Monelliopsis nigropunctata* (Granovsky), *Monellia caryella* (Fitch), and *Melanocallis caryaefoliae* (Davis) on the growth of pecan seedlings in the greenhouse. J. Economic Entomology 75:287-291.

46. Ware, L.M., and W.A. Johnson. 1958. Certain relationships between fertilizer and cultural practices, nitrate and moisture content of the oil, and responses to pecan trees. Proc. Southeastern Pecan Growers' Assoc. 51:10-17.
47. Watterson, G.P., and J.D. Stone. 1982. Parasites and blackmargined aphids and their effect on aphid populations in far-west Texas. Environmental Entomology 11:667-669.
48. White, A.W., E.R. Beaty, and W.L. Tedders. 1981. Legumes for supplying nitrogen and studies on legumes in pecan orchards. Pecan South 8(4):24-31.
49. Wood, B.W., and W.L. Tedders. 1982. Effects of an infestation of blackmargined aphid on carbohydrates in mature "Stuart" pecan. HortScience 17:236-238.
50. Wood, B.W., and W.L. Tedders. 1986. Reduced net photosynthesis of leaves from mature pecan trees by three species of pecan aphid. J. Entomological Sci. 21:355-360.
51. Wood, B.W., W. White, and W.L. Tedders. 1983. Use of legumes in pecan orchards. Annual Report Northern Nut Growers' Assoc. 74:147-150.
52. Wood, B.W., W.L. Tedders, and J.M. Thompson. 1985. Feeding influence of three pecan aphid species on carbon exchange and phloem integrity of seedling pecan foliage. J. Amer. Soc. Horticultural Sci. 110:393-397.
53. Wood, B.W., W.L. Tedders, and C.C. Reilly. 1988. Sooty mold fungus on pecan foliage suppresses light penetration and net photosynthesis. HortScience 23:851-853.

UPCOMING EVENTS

October 25-30, "Herbicide Action," an intensive course, will be held at Purdue University, West Lafayette, IN; contact Course Director, S.C. Weller, (765) 494-1333; or Conference Coordinator Kathy Hyman, (765) 494-2758; on the Internet, http://www.hort.purdue.edu

October 28-31, "Sustainable Community Development Strategies" will be held in Aspen, CO; contact JoAnn Glassier, Rocky Mountain Institute, Economic Renewal Seminar, 1739 Snowmass Creek Rd., Snowmass, CO 81654; (970) 927-3807; e-mail joann@rmi.org

November 5-7, "Food: Nature and Culture" will be held in New York City; contact the New School for Social Research, (212) 229-2488; e-mail kodeshn@newschool.edu

November 6-8, the Carolina Farm Stewardship Association's 13th Annual Sustainable Agriculture Conference will be held in Clemson, S.C.; contact Alyx Perry, CFSA, (919) 542-2402.

November 6-7, National Small Farm Trade Show & Conference will be held in Columbia, MO; contact Small Farm Today, 1-800-633-2535.

November 8, "New Crops & New Uses: Biodiversity & Agricultural Sustainability" will be held in Phoenix, AZ; contact David Dierig, Association for the Advancement of Industrial Crops, (602) 379-4356 ext. 265; e-mail ddierig@uswcl.ars.ag.gov

November 15-19, "Beyond Growth: Policies and Institutions for Sustainability" will be held in Santiago, Chile; contact International Society for Ecological Economics, phone 56-2-6782308, e-mail iseeconf@abello.dic.uchile.cl; on the Internet, http://www.uchilde.cl/facultades/ISEE3.html

November 16-17, "Celebrate Wildlife," the Wildlife Habitat Council's 10th Annual Symposium, will be held in Bethesda, MD; contact WHC, 1010 Wayne Ave., #920, Silver Spring, MD 20910; (301) 588-8994; e-mail whc@wildlifehc.org

November 16-19, 12th International Federation of Organic Agriculture Movements Scientific Conference will be held in Mar del Plata, Argentina; contact IFOAM, phone 49-6853-30110; e-mail IFOAM@T-online.de; on the Internet, http://ecoweb.dk/ifoam

December 5-6, "Diversified Vegetable Production & Management for Small & Large-Scale Organic Farmers"; **January 16-17, 1999,** "Biological Principles of Organic Agriculture"; and **February 20, 1999,** "Creating Successful Grower Marketing Cooperatives" will be held in Albany, NY; contact Regional Farm & Food Project, 27 Elm St., Albany, NY 12202; (518) 426-9331.

December 8, "Risks and Opportunities for California Agriculture" will be held in Sacramento, CA; contact Agricultural Issues Center, University of California Davis, (503)752-2320; e-mail agissues@ucdavis.edu

December 8-10, "Dairy Feeding Systems: Management, Components, and Nutrients" will be held in Camp Hill, PA; contact Northeast Regional Agricultural Engineering Service, 152 Riley-Robb Hall, Ithaca, NY 14853; (607) 255-7654; e-mail NRAES@CORNELL.EDU

December 10, "Farming Profitably in a Changing Environment" will be held in Urbana, IL; contact Deborah Cavanaugh-Grant, University of Illinois at Urbana-Champaign, Agroecology Sustainable Agriculture Program, (217) 968-5512; e-mail cavanaughd@ces.aces.uiuc.edu

January 20-23, 1999, 19th Annual Ecological Farming Conference will be held in Pacific Grove, CA; contact Committee for Sustainable Agriculture, 406 Main St., #313, Watsonville, CA 95076; (408) 763-2111.

January 23, 1999, Captain Cook, Hawaii; **March 20, 1999,** Big Cypress National Preserve, Florida; **July 23-25, 1999,** Frank Church River of No Return Wilderness area, Idaho; and **October 8-10, 1999,** Rutland, Ohio; "Planting the Future" conferences will be held about at-risk native medicinal plants; contact United Plant Savers, P.O. Box 98, E. Barre, VT 05649; (802) 479-8925; e-mail info@plantsavers.org

January 29-31, 1999, 18th Annual Organic Conference & Eco-Products Trade Show will be held at the University of Guelph, Canada; contact Tomas Nimmo, Box 116, Collingwood, Ontario, Canada L9Y 3Z4; (705) 444-0923; e-mail organix@georgian.net

February 22, 1999, 30th Annual North American International Erosion Control Association Conference and Trade Exposition will be held in Nashville, TN; contact IECA, 1-800-455-4322; e-mail ecinfo@ieca.org

Agronomic and economic performance of wheat and canola-based double-crop systems

Emily E. Pullins and Robert L. Myers

Abstract: *Double-cropping provides a method of diversifying the rotation, maximizing production, and increasing the profit potential of a cropping system. We assessed agronomic and economic performance of five alternative crops in comparison to the no-till wheat-soybean double-cropping system prevalent in the southern Corn Belt. Canola has shown potential as a profitable winter crop, but its effects on the subsequent crop in a no-till double-crop system required further study. Amaranth, buckwheat, sunflower, and pearl millet were planted after the harvest of canola or wheat, or after fallow. Alternative double-crop grain yield, production costs, and net returns were compared with those of double-crop soybean.*

Wheat yielded more than canola. Sunflower grain yields did not differ significantly after winter-crop treatments at any site. Yields of amaranth, buckwheat, soybean, and pearl millet differed after winter crops at some sites. At three study yield levels, net returns were positive and greatest for double-crop wheat-amaranth, canola-amaranth, wheat-sunflower, and canola-sunflower systems. All double-crop systems except canola-pearl millet had positive net returns at median study yield levels. Low or negative net returns resulted from the combination of low yield and low price for some double crops. Canola was shown to be an economically feasible alternative to wheat in a double-cropping system for central and southern Missouri. Buckwheat and sunflower were shown to be agronomically and economically competitive alternatives to soybean following either canola or winter wheat, with buckwheat most valuable in late-season planting conditions.

Key words: alternative crops, cropping systems, no-till, amaranth, buckwheat, canola, sunflower, pearl millet, soybean, wheat

Double-cropping of soybean (*Glycine max* [L.] Merr.) immediately after harvesting wheat (*Triticum aestivum* [L.] Thell) has been a common practice in the southern part of the Corn Belt, which includes Kentucky and the southern sections of Missouri, Illinois, Indiana, and Ohio (Lewis, 1976). Increasing the diversity of crops in a double-crop system can decrease economic risks for producers while increasing net returns. More efficient exploitation of land, nutrients, water, growing season, and equipment in double-crop systems may improve gross returns compared with a single full-season crop (Stinner and Blair, 1990).

Few alternatives to wheat and soybean have been examined for double cropping in the southern Corn Belt. Canola (*Brassica napus* L.) is a potential substitute for wheat as a winter crop. Canola is a rapeseed low in erucic acid, saturated fats, and glucosinolates, making it an ideal source of vegetable oil for human consumption (Holmes, 1980; Weber et al., 1991). Rising consumer demand for canola oil is not being met by domestic production. There are buyers for domestically grown canola, but there often are added costs for transportation, since collection points are widely scattered. Winter canola is planted using equipment and management techniques similar to those used for planting winter wheat. Winter wheat and canola have similar nutrient and water demands (Taylor et al., 1991; Knight et al., 1994). Wheat typically yields more than canola, but canola typically has a greater gross return, making it economically competitive with wheat.

Limitations with wheat-soybean double cropping include the availability of moisture and nutrients to the second crop and the length of the growing season required for both crops. Winter wheat growth and wheat residues increase or decrease the moisture available to the subsequent double crop (Minor et al., 1983; Langdale et al., 1990; Daniels and Scott, 1991). Nutrient availability to the second crop may be reduced or improved by decomposition of wheat and canola residue (Horricks, 1969; Rice, 1979; Hairston et al., 1987). Double crops are planted later than full-season crops because the winter

Contribution from the Missouri Agricultural Experiment Station Journal Series No. 12343.

E.E. Pullins was Research Assistant and R.L. Myers was Associate Professor, Department of Agronomy, University of Missouri, MO 65211. Current address of E.E. Pullins (corresponding author) is Department of Agronomy and Plant Genetics, University of Minnesota-St. Paul, 411 Borlaug Hall, 1991 Buford Cir., St. Paul, MN 55108); current address of R.L. Myers is Jefferson Institute, 601 Nifong Blvd., Ste. 5A, Columbia, MO 65208.

Table 1. Fertilization for wheat and canola (kg/ha).

	Columbia						New Franklin	Portageville		
	1992-1993			1993-1994			1994	1994		
	N	P	K	N	P	K	N	N	P	K
Fall	34	123	45	56	56	56	56	56	56	56
Spring	90			56			56	56		

crop must reach maturity before the second crop is planted. Later planting dates for double-crop soybean in this region typically reduce yields compared with full-season soybean (Minor et al., 1983).

Double crops in Missouri are planted from late June to early July, after wheat harvest. Successful alternatives to double-crop soybean must produce a grain yield within a shortened growing season and with limited available water for germination and early growth. It is preferable for all double crops to use the same equipment and similar management methods as the wheat-soybean double crop system.

Amaranth (*Amaranthus* spp. L.) is a pseudocereal high in lysine that shows a reduced yield with later planting dates in Missouri (Myers, 1996). Amaranth has a high protein content and higher lysine content than other cereal grains (Bressani, 1989), making it valued in the specialty food market as an ingredient in cereals, breads, crackers, and cookies. Current markets for amaranth are small, and only a few small companies process it. Most amaranth is processed into flour, but some grain is sold directly by farmers to consumers. Production practices and costs for amaranth are similar to those of sunflower. Its price is higher than that of other grains if a producer has a buyer or marketing arrangement.

Buckwheat (*Fagopyrum esculentum* Moench.) is commonly known as a flour component in baked goods and in soba-style noodles made in Japan. Buckwheat is being increasingly recommended as a double crop for Missouri in response to solid and expanding domestic and export markets (Myers and Meinke, 1994). The short growing season for buckwheat makes it a valuable crop for late planting. Production practices and potential returns for buckwheat are similar to double-crop soybean, as the grain is typically planted in narrow rows and is combine-harvested with a grain head. The price of buckwheat is slightly higher than for soybean, but its yield may be lower.

Sunflower (*Helianthus annuus* L.) is typically grown in Missouri for use in birdseed mixes (Myers and Minor, 1992). Future markets for sunflower include expanded use of specialty varieties as a component in snack foods, bird seed mixes, baked goods, and specialty oils. Also, byproducts from oil extraction and confectionery manufacture can be fed to livestock. Sunflowers have slightly higher production costs than soybeans, primarily because of the extra nitrogen and equipment necessary with sunflower. The price of sunflower fluctuates with the prices of soybeans and other oilseeds. Premiums are paid for specialty sunflowers, such as confectionery seeds or varieties with oil high in oleic acid.

Pearl millet (*Pennisetum glaucum* L.) was domesticated in Africa, where it is an important grain for human consumption (Hussain et al., 1988). Although it can be used as a feed grain, in the U.S. it has been limited to use as forage for livestock. However, it is beginning to be used as a grain crop in the U.S. In Georgia, pearl millet recently began to be used by large-scale poultry operations as a component of chicken feed. Production practices for pearl millet are similar to those of soybean,

Table 2. Dates and rates of planting and harvest at three locations from 1992-1994.

	Variety	Rate (kg/ha)	Row Spacing (cm)	Date of Planting	Date of Harvest
		Winter Crops			
Canola	Ceres	9	19	4-30 Sept	21-29 June
Wheat	Pioneer 2548	123	19	30 Sept - 9 Oct	21-29 June
		Summer Crops			
Amaranth					
1993	Plainsman	2	76	21 June - 1 July	12 Oct
1994	"	"	"	"	10-20 Sept
Buckwheat					
1993	Windsor Royal	56	19	13 July	12 Oct
1994	"	"	"	21-29 June	1-29 Sept
Soybean					
1993	Pioneer 9442	56-67	76	21 June - 1 July	25 Oct
1994	"	"	"	"	7-20 Oct
Sunflower					
1993	Cadillac	22	76	21 June - 1 July	12 Oct
1994	"	"	"	"	10-20 Oct
Pearl Millet					
1993	HGM 100	4.5	76	21 June - 1 July	12 Oct
1994	"	"	"	"	10-31 Oct

except that it requires nitrogen fertilizer and may require cultivation for weed control because no herbicides are labeled for use on it. The price of pearl millet is reflective of its nutritional quality.

Our objectives in this study were to determine the agronomic and economic potential of both canola as a substitute for wheat as a winter crop, and of amaranth, buckwheat, sunflower, and pearl millet as alternatives to soybean after the harvest of canola or wheat.

Materials and Methods

Design and analysis

We established a field site in fall 1992 at the University of Missouri-Columbia (UMC) Agronomy Research Center in Columbia, Missouri, on a Mexico silt loam (Udollic Ochraqualfs, fine montmorillonitic, mesic). Two sites were added in 1993: the UMC Delta Research Center at Portageville, Missouri, on a Steele sandy loam (Aquic Udifluvents, sandy over clayey, mixed, nonacid, thermic), and the UMC Horticulture Research Center at New Franklin, Missouri, on a Menfro silt loam (Typic Hapludalfs, fine-silty, mixed, mesic).

We used a randomized complete-block split-block design. Winter-crop main plots and double-crop subplots were randomized in four replications at each site. Grain yields were analyzed using single-factor ANOVA procedures. Means were separated at the 5% probability level using Fisher's Protected LSD.

Winter crop management

Sites were either plowed or chiseled and then cultivated twice with a disk in fall 1992 and 1993. We took soil samples before planting winter crops at all sites and analyzed for pH and nutrient content. Bray 1-extractable P and ammonium acetate-extractable K amounts were determined for soils at all sites.

On the basis of soil test results, we applied N, P, and K preplant at all locations (Table 1). Fall-applied fertilizers were broadcast before a final pass was made with a cultipacker. Both wheat and canola were topdressed with ammonium nitrate in the spring at all three sites.

We harvested winter crops using the same equipment (Table 2). A 1.5-m wide strip of each main plot was harvested after ends were trimmed to avoid border effects. We measured seed moisture at the time of harvest and adjusted grain yields to 9% moisture for canola and 13.5% for wheat. Immediately after harvest, stubble was mowed with a rotary mower to a height of about 8 cm.

Double-crop management

Seeding rates and row widths for double crops varied (Table 2). We planted buckwheat with a Tye no-till drill in 19-cm rows. The other four double crops were planted no-till in 76-cm rows using a Wintersteiger plot planter with John Deere 2.5-cm fluted no-till coulters to control weeds.

In some subplots, residue or patches of high moisture prevented the furrow from closing. Sections of subplots with poor initial emergence were hand-planted up to two weeks after mechanical planting. To compensate for drought conditions, 2.5 cm of water was applied at Columbia on 11 and 25 July, and 25 and 30 August 1994, using a linear-move sprinkler system.

We applied the postemergent herbicide sethoxydim (2-[1-(ethoxyimino)-butyl]-5-[2-(ethylthio)-propyl]-3-hydroxy-2-cyclohexen-1-one) across-the-top at 0.21 kg/ha to four double crops (not pearl millet) on 19 July 1993 for control of giant foxtail (*Setaria faberi* Herrm.). At all sites in 1994, glyphosate (isopropylamine salt of [*N*-(phosphoro-methyl)glycine]) was applied across-the-top immediately after planting at the recommended rate of 0.85 kg/ha, mixed with 2 l of non-ionic surfactant in 94 l H_2O/ha. In addition to hand hoeing, a wide-row chisel was used once in July at each site to reduce weed pressure.

Double crops, except pearl millet, were harvested with a Wintersteiger Nursery Master Elite combine. A 1.5-m wide strip of each plot was harvested after ends were trimmed to reduce border effects. Split plots of double crops with row lengths of 1 m or more were measured for yield adjustment in 1994. Buckwheat was harvested mechanically, except at Portageville. Lodged amaranth grain heads and late-maturing pearl millet heads were hand harvested and threshed with the combine. Grain moisture was determined for all crops at harvest, with those above 20% dried before threshing. Grain yields were adjusted to standard moisture contents: amaranth to 10%, buckwheat to 16%, soybean to 13%, sunflower to 9%, and pearl millet to 13%.

Early harvests of double crops were necessary to reduce losses from lodging and to coincide with harvest of other double crops at distant sites (Table 2). All crops had reached physiological maturity before harvest.

Precipitation

Rainfall during the cool season (October through May) for both 1992-1993 and 1993-1994 was near the 30-year average for all sites (Table 3). In 1993, record high rainfall and flooding predominated through the June-September growth period in central Missouri. The New Franklin site for 1992-1993 was lost because of standing water on winter crops through the harvest period. At Columbia in 1993, precipitation for the warm season was double the 30-year average. As a result, germination and early seedling growth were reduced, and preemergent herbicides could not be applied at planting. Precipitation in 1994 at Columbia and Portageville was near normal. Irrigation was used in July and late August at Columbia, however, as 59% of warm season precipitation was concentrated in early August. Rainfall at New Franklin in 1994 was lower than normal but no irrigation was possible at the site, so that the double crops were drought-stressed, particularly in July.

Economic analysis

We based average grain yields for all crops on yields from the double-crop study, and compared revenue with an estimate of the production cost for each crop. Wheat, soybean, and sunflower prices were based on prices received by producers in fall 1994 in Missouri. Amaranth, buckwheat, canola, and pearl millet prices were based on 1994 prices quoted by buyers of these crops.

We developed budgets for each alternative double crop. Variable expenses were based on actual material costs in Missouri. Fertilizer costs were obtained from local distributors in winter 1995. Fertilizers in January 1995 were quoted at the following

Table 3. Relative rainfall at the experimental sites (% of normal).

Location	Cool Season 1992-1993	Warm Season 1991	Cool Season 1993-1994	Warm Season 1994
Columbia	105[1]	236	106	105
New Franklin	-	211	109	64
Portageville	-	-	101	106

[1] Departures are calculated using 1961 to 1990 average from each location. Cool-Season crops use precipitation from October to May, warm-seasong crops from June to September

Table 4. Grain yields of two winter crops and five double crops after winter-crop treatments (kg/ha).

	Columbia		New Franklin	Portageville
Winter Crop	1993	1994	1994	1994
		Winter Crop Yield		
Canola	2182b[1]	1987b	3247b	2722b
Wheat	2814a	5300a	3571a	7421a
		Amaranth Yield		
Canola	1333b	844ab	1268a	545a
Fallow[2]	1849a	1518a	1430a	636a
Wheat	1346b	605b	1163a	696a
		Buckwheat Yield		
Canola	665b	1582a	857a	1253a
Fallow	1181a	1352a	827a	1372a
Wheat	799ab	1459a	755a	983a
		Soybean Yield		
Canola	2184a	1758b	1399a	681b
Fallow	1931a	2822a	1967a	2064a
Wheat	2093a	1949b	338a	2136a
		Sunflower Yield		
Canola	2720a	2399a	1453a	1634a
Fallow	3029a	2330a	1552a	1902a
Wheat	2093a	2304a	1236a	1640a
		Pearl Millet Yield		
Canola	1647ab	338a	1425a	-
Fallow	3786a	372a	1004a	-
Wheat	225b	259a	1056a	-

[1] Within a column, grain yield means followed by the same letter do not differ ($p<0.05$) using Fisher's Protected LSD.

[2] Fallow treatments demonstrate reduction or lack of effect on double-crop yield with use of a winter crop.

prices: N at \$0.59/kg; P at \$0.57/kg; and K at \$0.35/kg. As soybean is a nitrogen-fixing legume, no spring nitrogen cost was assumed for it. The same nutrient application rates were assumed for the canola- and wheat-based double-crop systems. The entire amount of P and K was applied in the fall to the winter crop.

Since current regulations limit pest control options for alternative crops, estimated weed control costs varied among the double crops. Herbicides have been labeled for use only on soybean, sunflower, and pearl millet double crops. As a result, these crops were assigned the cost of one application of preemergent or post-emergence herbicide, with costs taken from applications in the 1993-1994 experiment. Because there are several insects that often damage double-crop sunflower significantly, we assumed it received one application of insecticide.

Seed costs for winter and double crops were estimated using quotes from distributors for certified seed in 1994 and 1995. Labor costs were taken from published 1993 Missouri crop costs and 1995 projected crop budgets of full-season wheat, double-crop wheat-soybean, and wheat-sunflower systems (Moore, 1994). Because wide rows allow for cultivation in amaranth, it was assessed an additional \$8.00/ha for labor for increased cultural weed control. Mechanical weed control options in buckwheat are limited, since it is planted in narrow rows, so no additional labor charge was assessed. Buckwheat, pearl millet, and sunflower double crops were assumed to have the same labor costs as double-crop soybean. Canola was assumed to have the same labor cost as wheat.

We took machinery costs (fuel, oil, and repairs) from 1993 Missouri crop costs and 1995 projected crop budgets of full-season wheat, soybean, sunflower, and double-crop wheat-soybean or wheat-sunflower systems (Moore, 1994). Amaranth, buckwheat, and pearl millet were assumed to have machinery costs similar to soybean. A base cost for hauling of \$5.00/ha was included in machinery fuel cost for all crops. An additional cost of \$5.00/ha was assessed for lower test weight (canola and buckwheat), the added cost of handling small seed (amaranth, canola, and pearl millet), and longer transportation distance (amaranth, buckwheat, and pearl millet).

Miscellaneous costs were based on 1995 projected crop budgets for wheat, soybean, and sunflower in Missouri (Moore, 1994), and included any expected drying or storage costs for all crops. Amaranth, buckwheat, and pearl millet were assigned miscellaneous costs equal to those of soybean. Lubrication costs represent 15% of the total machinery operating costs, according to a formula from the Missouri Farm Planning Handbook (1986). Following Moore's procedures (1994), operating interest was calculated as 10% of one-half of total operating costs.

Land charge was based on 1990-1994 state average cash rents for cropland (Worm and Pauley, 1994).

Results and Discussion

Winter (first) crop

Wheat had a higher yield than canola at all sites (Table 4), and at Columbia and Portageville yields were above the 1994 state average of 3778 kg/ha (Table 4). High and low yields represent the highest and lowest yields in the study of the corresponding winter crop at four locations. Median yields are the midpoint between the low and high study yield values. Weather at both locations in 1993 and 1994 promoted growth of the winter crops.

Wheat yield at Columbia in 1993 and at New Franklin in 1994 was lower than average for the state, possibly because of warm and wet conditions in May 1993 that promoted scab and leaf rust in wheat, reducing grain fill and seed set (Smith, 1993). Yield of wheat at New Franklin in 1994 may have been reduced because difficulties with the no-till planter caused lower seeding rates.

Yield of canola in 1993 and 1994 at Columbia may have been reduced by disease pressure. Sclerotinia stem rot (caused by *Sclerotinia* sp.) infected areas of the plots at all sites and was the most damaging disease. Stem rot aged the seed heads prematurely, resulting in seed loss from lodging and shattering.

Winter wheat typically has a narrow profit margin unless grown as part of a double-crop system. With average yields, wheat-based double-crop systems had greater net returns than corresponding canola-based double-crop systems, which reflects canola's lower yield potential under ideal conditions. However, our results show that canola can serve as an economically competitive alternative to winter wheat in double-crop systems. Markets for canola oil and by-products are being expanded, including industrial applications and use of the meal for livestock feed.

Both canola and wheat can be winterkilled, but this is more likely with canola than wheat in the lower Midwest. The analysis of canola in this study does not incorporate the higher risk of winter kill, but it is a factor when producers consider canola. Improved management techniques and varieties are gradually reducing the risk, which will help with producer acceptance.

Grain yields of double (second) crop

The preceding winter crop did not significantly affect the yield of sunflower at any site, or yield of any crop at New Franklin (Table 4). Of nineteen site-crop combinations, yield of the double crop in thirteen was not affected by the preceding winter crop. Of the six site-crop combinations affected by preceding winter crop, five had improved double-crop yields following fallow. Only two site-crop combinations yielded less after both winter crops: amaranth at Columbia in 1993, and soybean at Columbia in 1994. At Columbia in 1993, buckwheat and pearl millet yielded higher after fallow than after canola or wheat, respectively. In 1994, amaranth yielded higher after canola than wheat at Columbia, and soybean yielded higher after wheat than canola at Portageville.

Differences observed at Columbia in 1993 for amaranth, buckwheat, and pearl millet may have been due to a positive effect of fallow under high precipitation. Grazing by geese on amaranth and soybean seedlings at Columbia in 1994 may have resulted in uneven stands and yield differences for all crops, especially amaranth and soybean. Low yield of soybean at Portageville in 1994 was due in part to the presence of volunteer canola.

Economic returns

Total cost of production was greatest for canola and wheat (Table 5). Land cost was assessed only for the winter crop, as producers would do who were considering the feasibility of adding a double crop to their typical winter-crop systems. Of the five double crops, soybean had the lowest cost of production, since it required no nitrogen fertilizer, insecticides, or additional transportation costs.

At low yield levels, double-crop systems had negative net returns for winter crops (Table 6), buckwheat, pearl millet, and soybean (Table 7). At high and median yield levels, net returns for all crop combinations were positive, except pearl millet following canola. Net returns above variable and fixed costs were positive and greatest for wheat-amaranth, canola-amaranth, wheat-soybean, and wheat-sunflower systems. Net return at high and median yield levels was positive in wheat-soybean, wheat-buckwheat, and canola-soybean systems. Net return was low or negative in wheat-pearl millet, canola-buckwheat, and canola-pearl millet systems, largely reflecting the low study yields or low prices.

Amaranth. The high price for amaranth gave amaranth double-crop systems the highest potential net return of all double-crop options. Net return with double-crop amaranth was competitive with double-crop soybean. More labor and transportation costs were included in the variable costs for double-crop amaranth (Table 5). Lodging and the absence of labeled herbicides required an estimated 8 hr/ha of labor for amaranth cultivation and harvest. Increases in amaranth production may lower the price to $0.50/kg, which would reduce the net returns estimated here by up to 50%, but leave them above double-crop soybean. The nutritional quality of amaranth gives it the potential to expand into major markets for use in products for human consumption. In addition, the unusually small size of amaranth starch granules increases its potential uses. Lack of market demand for amaranth in the U.S. has limited production to less than 2000 ha annually during the last several years, so amaranth now is an option only for a few producers.

Buckwheat. Net returns for buckwheat double-crop systems were lower than for amaranth, soybean, and sunflower at comparable yield levels. The higher production cost for buckwheat compared with soybean is due to higher seed cost and an application of nitrogen that soybean does not receive (Table 5). As an emergency crop for late planting, buckwheat produces a positive net return after canola and wheat at high to median yield levels. Increased flexibility in planting date makes buckwheat an acceptable alternative to double-crop soybean despite its lower yield and net return. Buckwheat potentially can be used in a wide variety of food and feed products, but its potential industrial uses have not yet been explored.

Sunflower. Double-crop sunflower

Table 5. Estimated total variable and fixed costs of two winter crops and five double-crops in Missouri ($/ha).

Crop	Canola	Wheat	Amaranth	Buck-wheat	Soybean	Sun-flower	Pearl Millet
Variable Costs							
Fertilizer[1]	84.56	84.56	33.04	33.04	0.00	33.04	33.04
Herbicide	0.00	0.00	0.00	0.00	20.64	20.64	19.76
Insecticide	0.00	0.00	0.00	0.00	0.00	24.70	0.00
Seed	54.34	49.40	49.40	49.40	32.11	37.05	24.70
Labor	37.00	37.00	60.00	52.00	52.00	52.00	52.00
Machinery fuel, oil, repairs	44.50	44.50	54.30	54.30	54.30	49.50	54.30
Lubrication	6.68	6.68	8.15	8.15	8.15	7.43	8.15
Transportation[2]	5.00	0.00	15.00	10.00	0.00	5.00	15.00
Miscellaneous	14.00	14.00	17.00	17.00	17.00	12.00	17.00
Interest	2.26	2.11	2.20	2.07	1.84	2.25	2.07
Total	248.34	238.25	239.09	225.96	186.04	243.60	226.02
Fixed Costs							
Land	153.74	153.74	0.00	0.00	0.00	0.00	0.00
Total Costs	402.08	391.99	239.09	225.96	186.04	243.60	226.02

[1] Fertilizer costs here do not correspond to study application rates. These costs represent an average expected application rate across regional soil-type variation and previous crop, whereas amounts applied in the study were site-specific following soil test recommendations. N, P and K were applied at winter crop planting, at the same rates for canola and wheat. No spring N cost was assumed for soybean.

[2] Based on the cost of hauling for soybean or wheat, $5.00/ha was included in machinery fuel cost estimates for all crops. Costs assessed to transportation reflect the additional costs incurred in transportation because of lighter weight, smaller seed size, and greater distance to elevator.

Table 6. Winter crop net returns at three study yield levels ($/ha).

Yield	Yield (kg/ha)	Price ($/kg)	Gross Revenue	Production Cost	Net Return
			Canola		
High	3247[1]	0.18	584	402	182
Median	2617[2]	0.18	471	402	69
Low	1987	0.18	358	402	-44
			Wheat		
High	7421	0.13	965	392	573
Median	5117	0.13	665	392	273
Low	2814	0.13	366	392	-26

[1] High and low yields represent the highest and lowest yields in the study following the corresponding winter crop at four site-year combinations (Table 4).

[2] Median yields are the midpoint of the low and high study yield values.

had higher net returns than double-crop buckwheat, soybean, and pearl millet at all yield levels after wheat or canola winter crops (Table 7). Double-crop sunflower, unlike soybean, had a positive net return at the lowest yield levels. Lower net returns for double-crop soybean reflect study yields that were below the statewide average for 1989 to 1993 (Worm and Pauley, 1994). Median yields in the study were within the range expected in Missouri (Myers and Minor, 1992). Production cost for sunflower was 22% greater than for soybean, in part because of additional nitrogen and insecticide applications on sunflower (Table 5). Prices given here are those offered by regional processors under contracts for varieties high in oleic acid. The prices of sunflower and canola fluctuate with the price of soybean, with a corresponding variation in available markets for the crop. Some oilseed-type sunflower also has been used by regional birdseed processors. Increased industrial use of specialty varieties has opened new markets for the crop.

Pearl millet. Poor yields combined with low prices resulted in a negative net return for pearl millet after canola at median study yield levels. Cost of production for double-crop pearl millet is similar to that of double-crop soybean (Table 5), so its poor ability to compete economically is due primarily to low potential yield and price. Pearl millet probably needs additional breeding efforts to produce varieties that consistently yield enough to make it a competitive double-crop option. Possible future uses for the crop include livestock feed, birdseed mixes, and products for human consumption. The market for pearl millet most likely will expand, but only slowly until further research makes it more economically viable.

Conclusions

In this study, canola consistently yielded less than wheat at every site. Compared with fallow, both canola and wheat winter-crops may have no effect or a negative effect on yield of the second crop. Buckwheat and sunflower were the most agronomically successful alternative double-crops in this study, and could be recommended for use in double-crop systems in the lower Midwest.

All double-crop systems had greater returns when the winter crop was wheat rather than canola, reflecting the high average yields of wheat at two locations in 1994. Three of the four alternative double crops were economically competitive with soybean after canola or wheat. Amaranth

Table 7. Double crop and double-crop system costs and net returns ($/ha) at three study yield levels.

Yield Level[1]	Double-crop Yield (kg/ha)	Price ($/kg)	Revenue	Cost	Net Return	Winter Crop Net Return	Total Net Return
			Canola-Amaranth				
High	1333	0.88	1173	239	934	182	1116
Median	939	0.88	826	239	587	69	656
Low	545	0.88	480	239	241	-44	196
			Wheat-Amaranth				
High	1346	0.88	1184	239	945	573	1518
Median	975	0.88	858	239	619	273	892
Low	605	0.88	532	239	293	-26	297
			Canola-Buckwheat				
High	1582	0.24	380	226	154	182	336
Median	1123	0.24	270	226	44	69	113
Low	665	0.24	160	226	-66	-44	-111
			Wheat-Buckwheat				
High	1459	0.24	350	226	124	573	697
Median	1107	0.24	266	226	40	273	313
Low	755	0.24	181	226	-45	-26	-71
			Canola-Soybean				
High	2184	0.21	459	186	273	182	455
Median	1432	0.21	301	186	115	69	184
Low	681	0.21	143	186	-43	-44	-87
			Wheat-Soybean				
High	2136	0.21	449	186	263	573	835
Median	1237	0.21	260	186	74	273	347
Low	338	0.21	71	186	-115	-26	-141
			Canola-Sunflower				
High	2720	0.22	598	244	355	182	537
Median	2086	0.22	459	244	215	69	284
Low	1453	0.22	320	244	76	-44	32
			Wheat-Sunflower				
High	2304	0.22	507	244	263	573	836
Median	1770	0.22	389	244	146	273	419
Low	1236	0.22	272	244	28	-26	-2
			Canola-Pearl Millet				
High	1647	0.09	148	226	-78	182	105
Median	992	0.09	89	226	-137	69	-68
Low	338	0.09	30	226	-196	-44	-240
			Wheat-Pearl Millet				
High	1056	0.09	95	226	-131	573	442
Median	640	0.09	58	226	-168	273	105
Low	225	0.09	20	226	-206	-26	-232

[1] High and low yields represent the highest and lowest yields in the study following the corresponding winter crop at four site-year combinations (Table 4). Median yields are the midpoint of the low and high study yield values. Double-crop and total net returns may not correspond to details because of rounding.

and sunflower had greater net returns than soybean grown after either canola or wheat. Buckwheat had a lower net return than soybean after either winter crop, but would be profitable when conditions required late-season planting. Considering prices, available markets, and agronomic quality, buckwheat and sunflower appear to be the most promising double-crop alternatives to soybean. Further breeding efforts and market expansion would improve the suitability of amaranth and pearl millet for the lower Midwest.

Acknowledgment. We extend our appreciation to Dr. Harry C. Minor, Dr. Donald Van Dyne, and Lou Meinke for their technical assistance and efforts.

References

1. Bressani, R. 1990. Grain amaranth: Its chemical composition and nutritive value. In Proc. Fourth National Amaranth Symposium: Perspectives on Production, Processing, and Marketing, Minneapolis, Minnesota, 23-25 Aug. Agric. Extension Service, Univ. of Minnesota, St. Paul. pp. 19-34.
2. Daniels, M.B., and H.D. Scott. 1991. Water use efficiency of double-cropped wheat and soybean. Agronomy J. 83:564-570.
3. Hairston, J.E., J.O. Sanford, D.F. Pope, and D.A. Horneck. 1987. Soybean-wheat double cropping: Implications for straw management and supplemental nitrogen. Agronomy J. 79:281-286.
4. Holmes, M.R.J. 1980. The oilseed rape crop. In Nutrition of the Oilseed Rape Crops. Applied Sci. Pub. Limited, London, U.K. pp. 1-20.
5. Horricks, J.S. 1969. Influence of rape residue on cereal production. Canadian J. Plant Sci. 49:632-634.
6. Hussain, M.A., F. Sizaret, and K. Atkinson. 1988. Pennisetum glaucum. In Traditional food plants. FAO Food and Nutrition Paper 42. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 394-398.
7. Knight, J.D., N.J. Livingston, and C. Van Kessel. 1994. Carbon isotope discrimination and water-use efficiency for six crops grown under wet and dryland conditions. Plant and Cell Environment 17:173-179.
8. Langdale, G.W., R.L. Wilson, Jr., and R.R. Bruce. 1990. Cropping frequencies to sustain long-term conservation tillage systems. Soil Sci. Soc. Amer. J. 54:193-198.
9. Lewis, W.M. 1976. Double cropping soybeans after winter small grains. In L. Hill (ed). World Soybean Research. Proc. World Soybean Research Conference. Interstate Printers and Pub. Inc., Danville, Illinois. pp. 44-45.
10. Minor, H.C., Z.R. Helsel, and S. McCrate. 1983. Wheat-soybean double crop management in Missouri. Agric. Guide. Pub. 4953. Univ. of Missouri-Columbia Extension Service, Columbia.
11. Missouri Farm Planning Handbook. 1986. Manual 75. FM7000. Univ. of Missouri-Columbia Extension Service, Columbia.
12. Moore, K.C. 1994. 1993 Missouri m.i.r. crop costs, projected 1995 crop budgets. Dept. of Agric. Economics Pub. FM 94-1. Univ. of Missouri-Columbia Extension Service, Columbia.
13. Myers, R.L. 1996. Amaranth: New crop opportunity. In J. Janick and J. Simon (eds). Proc. Third National Symposium on New Crops, Indianapolis, Indiana, October 22-25. Amer. Horticultural Soc. Press, Alexandria, Virginia. pp. 126-138.
14. Myers, R.L., and H.C. Minor. 1992. Sunflower: An American native. Agric. Guide. Pub. G 4290. Univ. of Missouri-Columbia Extension Service, Columbia.
15. Myers, R.L., and L.J. Meinke. 1994. Buckwheat: A multi-purpose, short-season alternative. Agric. Guide. Pub. G 4306. Univ. of Missouri-Columbia Extension Service, Columbia.
16. Rice, W.A. 1979. Influence of the nitrogen content of barley and rape straw amendments on nitrogenase activity in waterlogged soil. Soil Biology and Biochemistry 11:187-191.
17. Smith G.S. (ed). 1993. 1993 Missouri winter wheat performance trials. The Integrated Pest and Crop Management Newsletter 3(22):1. Plant Sci. Unit, College of Agriculture, Food and Natural Resources, Univ. of Missouri-Columbia, and Lincoln Univ., Columbia.
18. Stinner, B.R., and J.M. Blair. 1990. Ecological and agronomic characteristics of innovative cropping systems. In Edwards, C.A., R. Lal, P. Madden, R.H. Miller, and G. House (eds). Sustainable Agricultural Systems. Soil and Water Conservation Soc., Ankeny, Iowa. pp. 107-122.
19. Taylor, A.J., C.J. Smith, and I.B. Wilson. 1991. Effect of irrigation and nitrogen fertilizer on yield, oil content, nitrogen accumulation and water use of canola. Fertilizer Resources Institute. J. Fertilizer Use Technologies 29(3):249-260.
20. Weber, J.A., R.L. Myers, and H.C. Minor. 1991. Canola: A promising oilseed. Agricultural Guide, Pub. G 4280. Univ. of Missouri-Columbia Extension Service, Columbia.
21. Worm, D., and V. Pauley (eds). 1994. 1994 Field crops: Acreage, yield, production and value, Missouri, 1989-1993. In 1994 Missouri Farm Facts. Missouri Agric. Statistics Service, Univ. of Missouri-Columbia Extension Service, Columbia. p. 16.

EUROPE STEERS CLEAR OF GENETICALLY ALTERED FOOD

Throughout the world last year, more than 30 million acres of commercial farmland were planted with genetically modified seeds—10 times as much as the year before—"but not one of those acres was in the 15 countries of the European Union," according to The New York Times.

European consumers "are in open revolt over the prospect of a future in which nature has somehow been altered by people holding test tubes....The debate here about how —and whether— to unleash the most powerful tools of modern biology says much about the cultural and philosophical differences between pragmatic and risk-ready American, where genetic technology that focuses on food has largely been accepted, and the far more reticent people of Europe." There are several reasons for the European conservatism: "a strong environmental movement rooted in the 19th-century philosophy that nature is as wise as man, a fear of drastic change, and the unusually large number of small farms still run by families who are reluctant to end practices that have been honed over centuries."

Soil Improvement Following Addition of Chipped Wood from Twigs

Roger Lalande, Valentin Furlan, Denis A. Angers, and Gilles Lemieux

Abstract. *Wood residues are applied to soils to improve their organic matter content and related biological, physical, and chemical properties. We monitored the changes in soil total C and N content, the bacterial, fungal and actinomycetal populations, and microbial biomass and activity during 20 weeks in the first season following the application of chipped wood from twigs (CWT), and as residual effects during the second growing season on a loamy soil (coarse loamy, mixed, frigid, Humic Fragiorthod) in Sainte-Brigitte-des-Saults (Québec) Canada. Wet-aggregate stability and the content of nutrients of the soil also were determined. Adding CWT stimulated the bacterial and actinomycetal populations very rapidly (within 8 weeks); in the second season the effect was less pronounced and gradually disappeared. The most significant and long-lasting effect was on the fungal population in two consecutive years of observation, with increases of up to 24-fold. This stimulation of fungi possibly was responsible for the large and significant increase in wet-aggregate stability observed in the second year. The effect of CWT on alkaline phosphatase activity and total C and N was observed only in the second season. Some NO_3^- immobilization was seen only in the season immediately following residue application. The addition of the CWT also supplied micronutrients, in particular Zn, which would make it a useful source of some elements in deficient soils. Application of CWT to this soil greatly improved its quality, as revealed by its biological, chemical, and physical attributes.*

Key words: microbial populations, soil structure, mineral content, soil bacteria, actinomycetes, fungi, soil organic matter

Soil organic matter plays an important role in soil fertility, both by being a reservoir of nutrients and by contributing to the cation exchange capacity of the soil. It also affects the physical characteristics of the soil and protects it from degradation. Furthermore, organic matter is the energy source for the decomposer community. According to Gregorich et al. (1994), soil organic matter is the single most important indicator of soil quality and productivity. It therefore is necessary to adopt agricultural practices that will maintain or increase soil organic matter levels to sustain crop productivity.

In response to environmental and social pressures, low-input sustainable agriculture has emerged as an alternative to more conventional practices. Consequently, different organic inputs have received close attention (Buchanan and Gliessman, 1991; Foshee et al., 1996). The application of organic residues is common, especially in developing countries, where they help reduce soil degradation and maintain soil organic matter at a level acceptable for crop production (Van den Beldt, 1990).

Chipped wood from twigs (CWT), which consists of small-diameter branches and twigs from certain tree or shrub species, are increasingly considered as a potential organic amendment in agricultural soils. In the province of Québec (Canada), the annual potential production of CWT is estimated to be at least 1.0×10^5 m^3. Currently, this material is burned or simply left on the ground. Trials have been performed to test the effectiveness of these residues as organic amendments on agricultural soils. N'dayegamiye and Dubé (1986) reported higher yields and lower N immobilization in different crops following three successive years of addition of wood bark, particularly in treatments supplemented with hog manure. CWT application under field conditions increased potato yield by up to 37% (C. Beauchamp, Département de Phytologie, Université Laval, personal communication, 1992). Aman et al. (manuscript in preparation) reported yield increases up to 300% on maize treated with CWT in Côte d'Ivoire (Africa). Other trials in tropical countries obtained significant yield increases on various crops treated with CWT from different plant species (Lemieux, 1986).

Because its high C:N ratio favors N immobilization by the microbial biomass, CWT may not appear advantageous to soil fertility, at least in the short run. Nevertheless, small-diameter branches and twigs are rich in sugars and nitrogenous compounds (starches, pectin, proteins, cellulose and nonpolymerized lignin). Following their fragmentation into small chips and their incorporation into soil, they

R. Lalande is Soil Microbiologist, V. Furlan is Mycorrhizologist, and D.A. Angers is Soil Scientist, Centre de recherche et de développement sur les sols et les grandes cultures, Agriculture et Agroalimentaire Canada, 2560, boul. Hochelaga, Sainte-Foy (Québec), Canada G1V 2J3; G. Lemieux is Professor, Département des sciences du bois et de la forét, Faculté de foresterie et de géomatique, Université Laval, Québec (Québec), Canada G1K 7P4. Corresponding author is R. Lalande (lalander@em.agr.ca).

Table 1. Macronutrients in chipped wood from twigs (g/kg).

	N	P	K	Ca	Mg
White birch	1.0	1.3	4.8	8.1	1.7
Sugar maple	0.7	0.9	3.6	5.8	0.9

Table 2. Micronutrients in chipped wood from twigs (mg/kg).

	Al	Na	Fe	Mn	Cu	Zn	B	Mo
White birch	46	<20	<90	327	<20	124	<20	<20
Sugar maple	<30	<20	40	32	<20	24	<20	<20

would release nutrients and be further degraded by soil microorganisms (Hendrickson, 1987).

The objective of this investigation was to follow for two years the impact of CWT on different soil biological properties, such as microbial biomass, microbial population and enzymatic activity, soil aggregate stability, and soil nutrient content.

Materials and Methods

Site and treatments

The field experiment was carried out in 1993 and 1994 on a vegetable farm at Sainte-Brigitte-des-Saults (46°02' N, 72°29' W), Québec. The soil was a sandy loam (coarse loamy, mixed, frigid, Humic Fragiorthod) with a pH (soil:water 1:1) of 6.2 and organic matter content of 5.8%. In the preceding years (1990 to 1992), leeks (*Allium porrum* L.) were cultivated on this soil, which was fertilized with inorganic fertilizer according to provincial recommendations (Conseil des Productions Végetales du Québec, 1982). The field had not received any organic amendment in the previous 10 years. The initial soil nutrient levels (ppm) with a Mehlich-III extraction (Simard et al., 1988) were: P, 68; K, 107; Ca, 988; Mg, 59; Fe, 325; Cu, 0.9; Zn, 1.2; and Mn, 47. The site had a mean temperature of 15.4 and 15.7° C (June to October 1993 and 1994, respectively) and precipitation of 105 mm and 81 mm during the same periods.

The two treatments were laid out in 1.3 × 1.3-m plots in a randomized complete block design with four replicates. On June 1, 1993, small twigs (≤5 cm in diameter) from white birch (*Betula papyrifera* Marsh.) and sugar maple (*Acer saccharum* Marsh.) (2:1 ratio), were chipped and spread over the treated plots (CWT+) at a rate of 600 m^3/ha. The CWT was incorporated into the soil to a depth of 12 to 15 cm using a rotocultivator. Control plots (CWT-), which did not receive any CWT, were cultivated in the same way. The experiment was continued in 1994 to evaluate the residual effects. Chemical characteristics of the woods used in the CWT mixture (Tables 1 and 2) were obtained with the method used by Grigal et al. (1976). Plots were planted in onions (*Allium cepa* L.) and wheat (*Triticum aestivum* L.) in the first and second year, respectively. Inorganic fertilizers were added in 1993 at the following rates: 110 kg N/ha as NH_4NO_3: 18 kg P/ha as 0-46-0; and 104 kg K/ha as 0-0-60. We also applied Mg at 77 kg/ha as $MgSO_4$; Cu at 4 kg/ha as $CuSO_4$; and Zn at 20 kg/ha as $ZnSO_4$. In 1994, only NH_4NO_3 (90 kg N/ha) was applied.

Plate counts, soil microbial biomass C, and phosphatase activity

In both years, soil sampling began in the first week of June and continued every 4 weeks after that for 20 weeks. Composite soil samples were collected in the 0-15 cm layer, sieved at 6 mm, placed in a cooler for transportation to the laboratory, and stored at 4°C until processing for analysis. A portion of the soil was air-dried, sieved at 2 mm, and finely ground. Total C and N were determined in the ground soil using a LECO CNS-1000 analyzer (Leco Instrument, St. Joseph, Michigan). Macro- and micronutrient contents on the air-dried sieved soil were analyzed following Mehlich-III extraction.

We counted each type of microbe by the spread plate technique the day after soil sampling. Dilution plate counts were prepared on the following media: tryptic soy agar for total bacteria (Difco); rose bengal-streptomycin agar for fungi (Martin, 1950); and starch-casein agar for actinomycetes (Kuster and Williams, 1964). Dilutions were prepared in peptone phosphate buffer (Vincent, 1970). Plates were incubated under aerobic conditions in the dark prepared at 25° C. Colonies were quantified after 5 days for fungi, 7 days for bacteria, and 14 days for actinomycetes. Microbial counts were determined in quintuple plates and expressed on an oven-dry soil basis.

We measured microbial biomass and enzyme activity within 2 weeks after soil sampling. We measured soil microbial biomass C using the chloroform fumigation-extraction method, and used a value of $k_c = 0.38$ to convert soluble C to microbial biomass C (Vance et al., 1987). Alkaline phosphatase activity was determined according to Tabatabai and Bremner (1969). All results are the means of three determinations, and are expressed on an oven-dry soil basis.

Wet-aggregate stability

To determine wet-aggregate stability (WAS), 10 g of field-moist aggregates (1-2 mm) was wet-sieved at 250 μm by direct and total immersion of aggregates for 10 min. The stability of aggregates was expressed as a percentage of total soil (oven-dry basis) after correction for sand content (Angers and Mehuys, 1993). Soil water content (WC) was determined after drying to constant weight at 105°C.

Statistical analysis

We analyzed the data separately for each sampling date, using the General Linear Model routine of SAS for a randomized complete block design (SAS Institute, 1990). For fungal counts, statistical analysis was performed on log-transformed data, so that the standard error of the mean (SEM) is not shown on the figure.

Results

All microbial counts showed significant ($p<0.05$) temporal variation following

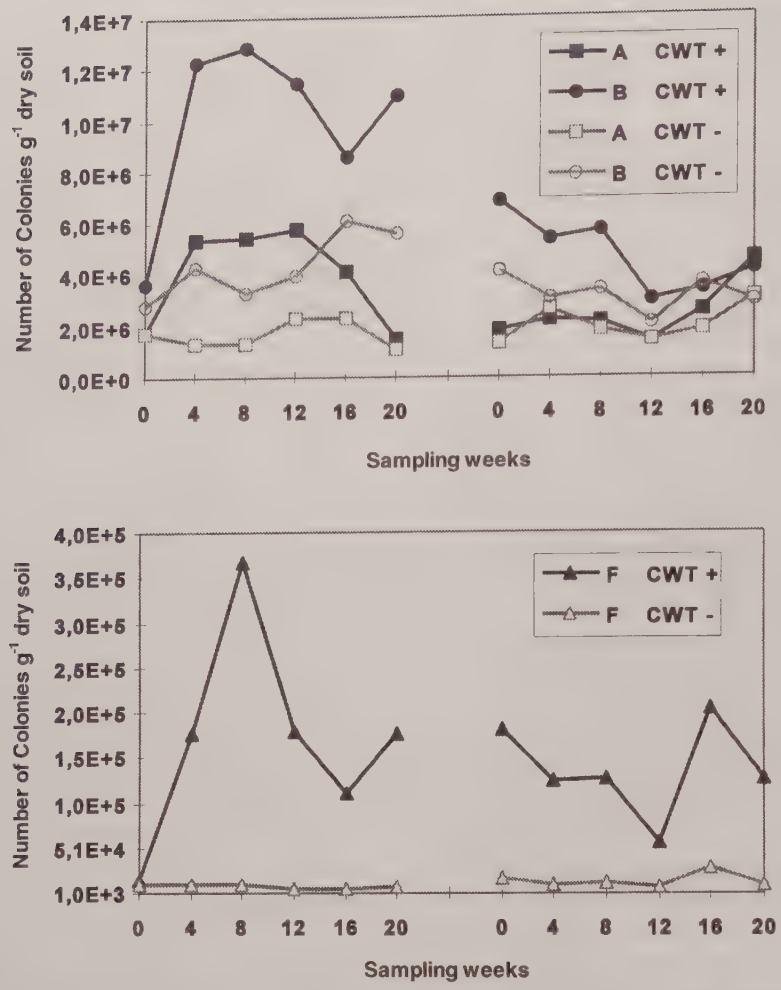


Figure 1. Populations of actinomycetes (A), bacteria (B) and fungi (F) in a sandy loam soil, 1993 (left) and 1994 (right), with (CWT+) and without (CWT-) application of chipped wood in 1993. Values are means of five Petri plates.

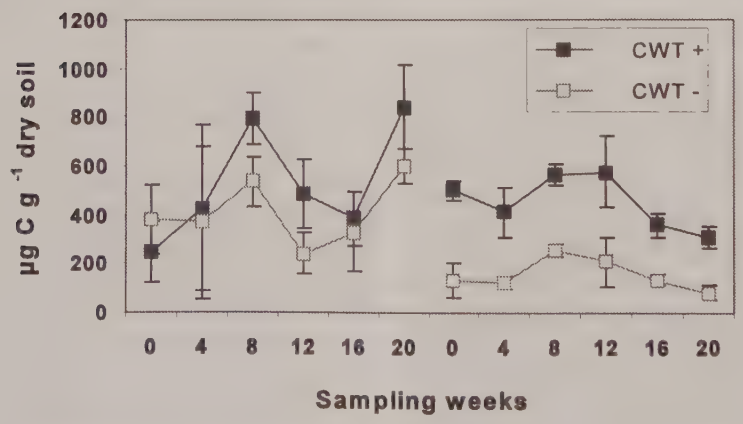


Figure 2. Microbial biomass C in a sandy loam soil, 1993 (left) and 1994 (right), with (CWT+) and without (CWT-) application of chipped wood in 1993. Values are means ± SEM.

CWT addition (Fig. 1). The highest numbers of both bacteria and fungi were observed in week 8 after the CWT application. During the 20-week sampling period in 1993, the bacterial population was consistently higher than the actinomycetal. The decrease seen in the actinomycetal population also occurred with the bacterial population, but the latter increased in week 20 (Fig. 1). Compared with the untreated plots (CWT-), CWT application increased bacterial and actinomycetal populations in the first year by 140% and 163%, respectively. The differences were significant ($p<0.05$) on all sampling dates. In the second year, CWT had a residual effect on the bacterial population, at least for the first three samplings, when the differences were statistically significant (Fig. 1). On average, during 1994 the bacterial and actinomycetal populations increased in the CWT+ plots by 48 and 21%, respectively, compared with the untreated ones.

Following CWT addition, the fungal population increased 24- and 8-fold in 1993 and 1994, respectively. The increases all were statistically significant ($p<0.05$). An abundant mycelial web was observed in the soil of treated plots (data not shown). Although the fungal population was lower than the bacterial and actinomycetal populations, as is usual, its relative response to CWT was greater (Fig. 1).

When compared with plate counts, microbial biomass C reflected well the temporal evolution of the bacterial and fungal populations after CWT application (Fig. 2). A similar pattern was observed during the first growing season and in the first three sampling dates of the second season.

We did not observe any significant effect of CWT application on alkaline phosphatase activity during the first season. For the entire second growing season, however, enzymatic activity in the CWT treatment increased significantly, by almost twofold (Fig. 3).

CWT application significantly ($p<0.05$) affected wet-aggregate stability on all dates (Fig. 4). The effect was more pronounced in the second year (an average increase of 50% over CWT-). Soil gravimetric water content was significantly higher in the treated soil. There was an inverse correlation between WAS and WC ($p<0.01$) in the first year but not the second.

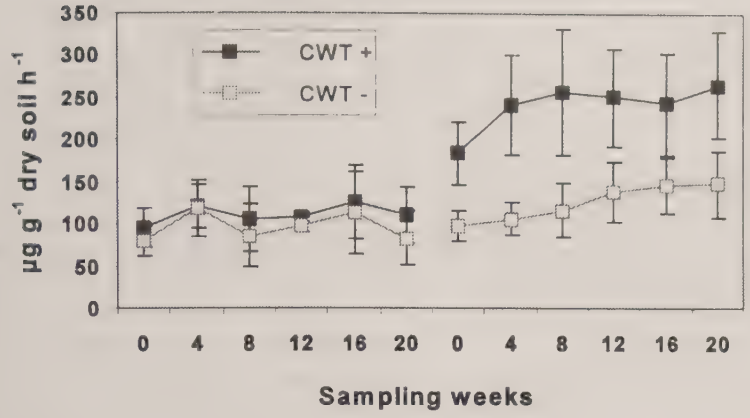


Figure 3. Alkaline phosphatase activity in a sandy loam soil, 1993 (left) and 1994 (right), with (CWT+) and without (CWT-) application of chipped wood in 1993. Values are means ± SEM.

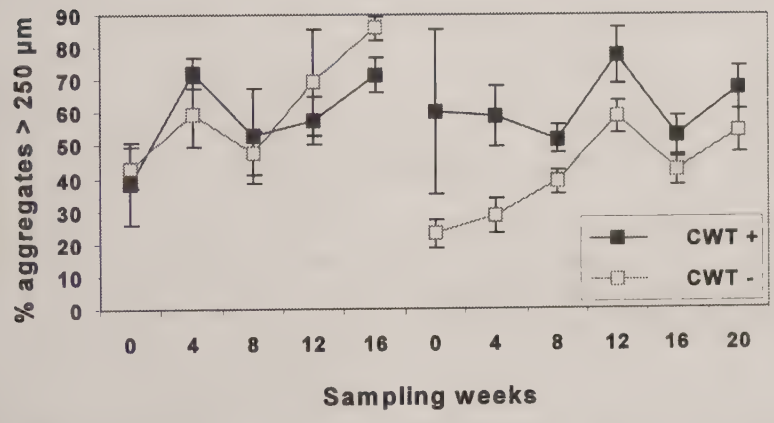


Figure 4. Water aggregate stability in a sandy loam soil, 1993 (left) and 1994 (right), with (CWT+) and without (CWT–) application of chipped wood in 1993. Values are means ± SEM.

The soil receiving CWT showed an increase in total C and N compared with the untreated soil, particularly during the second year, when some significant differences ($p<0.05$) were observed (Fig. 5). NO_3^- – N declined rapidly in the first year following the addition of CWT (Fig. 6). NO_3^- content was negatively correlated ($p<0.05$) with bacterial, fungal, and actinomycetal populations ($r = -0.64$, -0.54, and -0.48, respectively).

The 0-15 cm soil layer was consistently higher in Zn in the CWT+ than the CWT- plots in both years (Fig. 6). The other nutrients did not show any clear and consistent trends.

Discussion

Incorporation of CWT into the soil proved to be an excellent stimulus for all microbial populations, with the response of the fungi remarkably high, rapid, and long-lasting. This was to be expected, since wood, which contains cellulose, is preferentially attacked by fungi (Kokalis-Burelle and Rodriguez-Kábana, 1994). In the first stage of CWT decomposition, lignin is attacked by the Basidiomycetes, transformed into polyphenols and humic substances, and incorporated into soil organic matter (Garcia et al., 1987; Anderson, 1988; Smith et al., 1993). Therefore, organic amendments rich in cellulose and lignin increase the level of organic matter (Allison, 1973; Flaig, 1978; Smith et al., 1993), as was also seen in our study in the increase in total C and N in the second year.

Fungi are effective in increasing the stability of the soil macroaggregates larger than 250 µm (Tisdall and Oades, 1982). They are believed to be temporary organic binding agents that can provide physical stability by enmeshing soil particles. Fungi also produce mucilage and possibly other compounds that increase binding (Lynch and Bragg, 1985). The very high increase in fungal population following CWT addition, which was still very apparent in the second year, probably contributed to the stabilization of the >250 µm aggregates. The population of fungi, but not of actinomycetes or bacteria, was correlated with WAS ($p<0.01$) in the second year. According to Tisdall and Oades (1982), the stabilization of macroaggregates by fungi is limited to periods when large amounts of readily decomposable materials have been added to the soil, leading to a bloom of hyphal growth as was easily seen in our treated soil. The increase in the populations of microbes other than fungi also probably contributed to the production of polysaccharides and lipids, both of which contribute to soil stabilization after organic additions (Tisdall and Oades, 1982). N'dayegamiye and Angers (1993) studied the long-term effect (9 years) of annual application of similar material, but at much lower rates (<50 Mg ha^{-1} yr^{-1}). They found that wood residues significantly affected soil C content, but not aggregation.

The activity of soil enzymes may be inhibited by the addition of certain organic amendments. For instance, Perucci et al. (1984) found that the addition of organic residues (tomato [*Lycopersicon esculentum*], maize [*Zea mays*], or wheat straw) could inhibit several enzymes to some degree. In our study, CWT had almost no influence on alkaline phosphatase activity in the first year, and in fact increased it in the second year. The high Zn content of the residue did not seem to inhibit enzymatic activity, as might have been expected (Tyler, 1981).

The main practical problem with using lignin residues as soil amendments is their high C:N ratio, which can stimulate

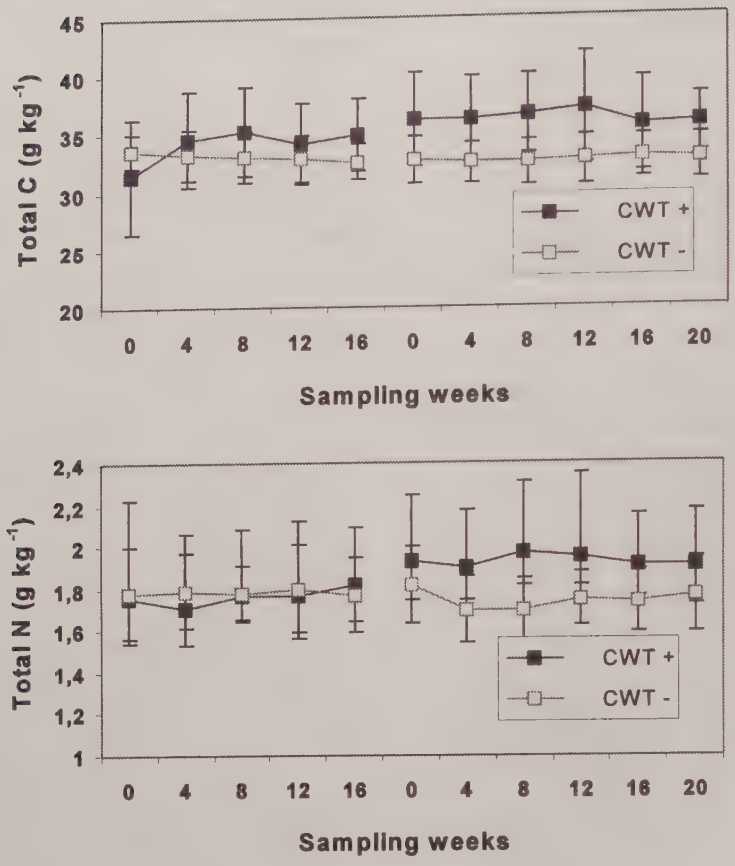


Figure 5. Soil total carbon and nitrogen in a sandy loam soil, 1993 (left) and 1994 (right), with (CWT+) and without (CWT-) application of chipped wood in 1993. Values are means ± SEM.

N immobilization by microorganisms and, therefore, be detrimental to the developing crop following incorporation (Sommerfeldt and MacKay, 1987). Our NO_3^- – N data suggest that some N immobilization occurred in the first year (Fig. 6). Moreover, the significant ($p<0.05$) negative correlations between NO_3^- – N and microbial populations suggest a decrease in NO_3^- – N with increasing population of microorganisms. No effect of CWT on NO_3^- was observed in the second year, which suggests that the N-immobilizing effect of CWT lasted only for the first year.

The ability of wood to accumulate mineral ions, at different levels according to species (Tables 1 and 2), also favors the use of CWT as a renewable resource. In this case, the supply of Zn seems to have been particularly significant.

Organic amendments have long been used to enhance soil quality. In this study, the addition of CWT stimulated the microbial population for at least two years, particularly fungi, with significant effects on soil aggregates and total C and N. This should be considered an important feature for sustainable resource management. Since wood can accumulate heavy metals, but at levels below what is harmful, this could be taken into consideration as a way to incorporate essential micronutrients into deficient soils.

Acknowledgment. We thank Roger Lévesque and Guy Pelletier for their enthusiastic technical assistance.

References

1. Allison, F.E. 1973. Soil Organic Matter and Its Role in Crop Production. Elsevier Scientific Publishers, Amsterdam, The Netherlands.
2. Anderson, J.M. 1988. Spatio-temporal effects of invertebrates on soil processes. Biology and Fertility of Soils 6:216-227.
3. Angers, D.A., and G.R. Mehuys. 1993. Aggregate stability to water. In M.R. Carter (ed). Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, Florida. pp. 651-657.
4. Buchanan, M., and S.R. Gliessman. 1991. How compost fertilization affects soil nitrogen and crop yield. BioCycle 32:72-77.
5. Conseil des Productions Végetales du Québec 1982. Légumes, Culture. Comité des cultures légumières. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, agdex 250/20, Québec, Qc., Canada.
6. Flaig, W. 1978. Biochimie de la matière organique du sol. In L'emploi des matières organiques comme engrais verts. No. 27. United Nations Food and Agriculture Organization, Rome, Italy. pp. 34-76.
7. Foshee, W.G., W.D. Goff, K.M. Tilt, and J.D. Williams. 1996. Organic mulches increase growth of young pecan trees. HortScience 31:811-812.
8. Garcia, S., J.P. Latge, M.C. Prévost, and M.S.A. Leisola. 1987. Wood degradation by white-rot fungi: Cytochemical studies using lignin peroxidase-immunoglobin-gold-complex. Applied and Environmental Microbiology 53:2384-2387.
9. Gregorich, E.G., M.R. Carter, D.A. Angers, C.M. Monreal, and B.H. Ellert. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian J. Soil Sci. 74:367-385.
10. Grigal, D.F., L.F. Ohmann, and R.B. Brander. 1976. Seasonal dynamics of tall shrubs in Northeastern Minnesota: Biomass and nutrient element changes. Forest Sci. 22:195-208.
11. Hendrickson, O. 1987. Winter branch nutrients in northern conifers and hardwoods. Forest Sci. 33:1068-1074.
12. Kokalis-Burelle N., and R. Rodriguez-Kàbana. 1994. Changes in populations of soil microorganisms, nematodes and enzyme activity associated

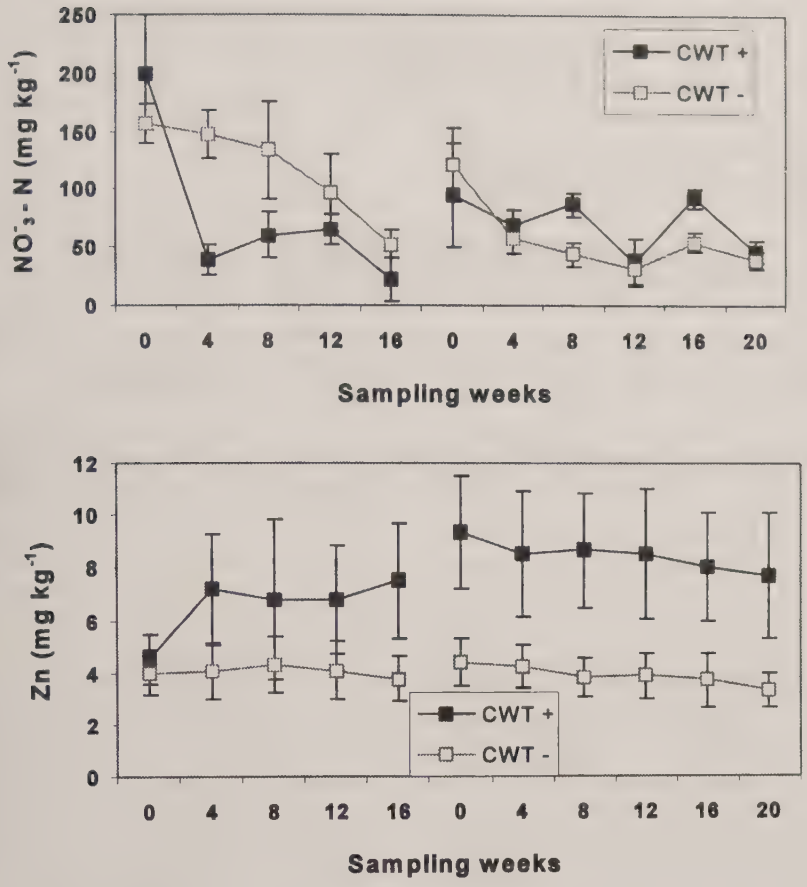


Figure 6. Soil nitrate content and zinc content in a sandy loam soil, 1993 (left) and 1994 (right), with (CWT+) and without (CWT-) application of chipped wood in 1993. Values are means ± SEM.

with application of powdered pine bark. Plant and Soil 162:169-175.

13. Kuster, E., and S.T. Williams. 1964. Selection of media for isolation of streptomycetes. Nature (London) 202:928-929.
14. Lemieux, G. 1986. Le bois raméal et les mécanismes de fertilité du sol. Ministère de l'énergie et des ressources, Direction de la sylviculture et Département des sciences du bois et de la forêt, Faculté de foresterie et de géomatique, Université Laval, Québec, Canada.
15. Lynch, J.M., and E. Bragg. 1985. Microorganisms and soil aggregate stability. Advances in Soil Sci. 2:133-172.
16. Martin, J.P. 1950. Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. Soil Sci. 69:215-227.
17. N'dayegamiye, N., and A. Dubé. 1986. L'effet de l'incorporation de matières ligneuses sur l'évolution des propriétés chimiques du sol et sur la croissance des plantes. Canadian J. Soil Sci. 66:623-631.
18. N'dayegamiye, N., and D.A. Angers. 1993. Organic matter characteristics and water-stable aggregation of a sandy loam soil after 9 years of wood-residue applications. Canadian J. Soil Sci. 73:115-122.
19. Perucci P., L. Scarponi, and M. Businelli. 1984. Enzyme activities in a clay-loam soil amended with various crop residues. Plant and Soil 81:345-351.
20. SAS Institute. 1990. GLM-VARCOMP, SAS/STAT User's Guide, vol. 2, version 6, 4th ed. Cary, N.C.
21. Simard, R.R., L.J. Evans, and T.E. Bates. 1988. Effects of addition of $CaCO_3$ and P on the soil solution composition of a Podzolic soil. Canadian J. Soil Sci. 68:41- 52.
22. Smith, J.L., R.I. Papendick, D.F. Bezdicek, and J.M. Lynch. 1993. Soil organic matter dynamics and crop residue management. In F.B. Metting (ed). Soil Microbial Ecology. Marcel Dekker, New York, N.Y. pp. 65-94.
23. Sommerfeldt, T.G., and D.C. MacKay. 1987. Utilization of cattle manure containing wood shavings: Effect on soil and crop. Canadian J. Soil Sci. 67:309-316.
24. Tabatabai, M.A., and J.M. Bremner. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biology and Biochemistry 1:301-307.
25. Tisdall, J.M., and J.M. Oades. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33:141-163.
26. Tyler, G. 1981. Heavy metals in soils: Biology and biochemistry. In E.A. Paul and J.N. Ladd (eds). Soil Biochemistry. Marcel Dekker, New York, N.Y. pp. 371-414.
27. Vance, E.D., P.C. Brookes, and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass carbon. Soil Biology and Biochemistry 19:703-707.
28. Van den Beldt, R.J. 1990. Agroforestry in the semiarid tropics. In K.G. MacDicken, and N.T. Vergara (eds). Agroforestry: Classification and Management. John Wiley & Sons, New York, N.Y. pp. 150-194.
29. Vincent, J.M. 1970. A Manual for the Practical Study of Root-nodule Bacteria. International Biological Programme Handbook no. 15. Blackwell Scientific, Oxford, U.K.

MERRIGAN NAMED VICE CHAIR OF ORGANIC STANDARDS BOARD

Kathleen Merrigan, the Wallace Institute's Senior Analyst, was elected Vice Chair of the National Organic Standards Board at the Board's last meeting in July. She was appointed to a five-year term in March, 1995. At the July meeting, the Board discussed the USDA's proposed rule for national organic standards, and its statutory authority over the National List of approved synthetic materials.

Examination of some microbiological and biochemical parameters and tests of product quality used in a long-term fertilization trial

Joachim Raupp

Abstract. *On the basis of investigations with samples from a fertilization trial started in 1980, some parameters of food storage ability are evaluated. Microbial infestation of the product during incubation seems to be the most reliable parameter, but the circumstances of infestation and the optimal test conditions are unknown. There are no reliable correlations among the results of degradation tests, storage tests under optimal conditions, and chemical contents of the product. The concept of product vitality (a product-oriented quality referring to a product full of vigor) is based on results of degradation tests. Ultimately, however, food quality standards are based on human priorities (human-oriented). Therefore, not only product characteristics, but also social, psychological, and environmental criteria should be considered.*

Key words: storage ability, food quality, degradation tests, quality assessment, organic farming, biodynamic agriculture

A simple approach to the evaluation of food quality is to analyze the product for individual beneficial or harmful chemical components. The idea is that food contributes to our metabolism by supplying chemical, physical and biochemical substances. A different idea is that food should support life—maintain our life processes—as Meier-Ploeger (1995) pointed out regarding the nutritional concepts of Werner Kollath, Max Bircher-Benner and Rudolf Steiner. She described the different concepts as based on a particular view of life that can be summarized by statements such as "life is influenced by terrestrial and cosmic factors, life is communication, life is building up and maintaining a form," etc. Obviously, these aspects of food could not be determined sufficiently by chemical analyses. Hence, more comprehensive approaches were needed, which frequently were developed or introduced by research connected with organic farming (e.g., Meier-Ploeger and Vogtmann, 1988). The reason for this connection might be that more than other agricultural methods, organic farming stresses the linkages among the production system, environmental impact, food quality, and human health. This view is confirmed by consumers' opinions and expectations about organically produced food as revealed by surveys (Alvensleben and Altmann, 1986; Baade, 1987; Wirthgen, 1987).

The comprehensive approaches to food quality seek to quantify the behavior of a product over time under the storage conditions encountered in practice or in model experiments. Storage behavior is regarded as an indicator of the vitality of a product, that is, the stability or dissolution of its "temporal structure" (Abele, 1987; Balzer-Graf and Balzer, 1988). To develop, improve, and standardize these tests requires samples of several crops from well-defined experimental treatments. Such data are available from long-term fertilization experiments carried out in Germany (e.g., Abele, 1987) and Sweden (reported by Granstedt and Kjellenberg, 1997). Besides chemical analyses, these experiments also have used microbial and biochemical tests from the beginning, although some of the results "cannot yet be interpreted definitively" (Abele, 1987, p. 7). Abele intended to give a stimulus to food quality research. Meanwhile, a body of results is available from the 17 years of a German fertilization trial, but no overall evaluation of results and test methods has been done.

In this paper I summarize the results of the biochemical and microbiological tests carried out with samples from the fertilization experiments. A critical evaluation takes into special consideration the problem of suitable parameters and analytical methods for quality assessment, as well as the conclusions based on the analytical data. What can we learn from these tests regarding a product's vitality, that is, its

Joachim Raupp is senior scientist (team leader, long-term trial), Institute for Biodynamic Research, Brandschneise 5, D-64295 Darmstadt, Germany; raupp@aol.com.

vigor and resistance against decomposition, and human-oriented quality criteria?

Description of the Tests

Degradation tests. Degradation tests are one of the oldest approaches to quantifying storage ability without a storage period of several months. (Samaras [1978] refers to publications from around 1940.) The product is cut into portions (slices) or grated, then incubated with replicates for 10 to 11 days at 20°C. The dry matter loss, carbon dioxide development, or visual modifications (changed color, growth of microbes) during incubation are taken as characteristics of the sample. The method of Samaras (1978) has been used in other studies with minor modifications: incubation at 30°C (Abele, 1987), just two days at 28°C (Wistinghausen, 1979) or five days at 22°C (Wistinghausen, 1984). These authors tested vegetables; other studies also used cereals (Spiess, 1978; Samaras, 1981). This test sometimes is called self-degradation, which is not really an appropriate term. Not only are the product's own enzymes involved in the decomposition, but also the epiphytic, nonspecific microflora.

Darkening of an extract. This test is carried out mainly with potatoes (*Solanum tuberosum*), in a method tracing back to Pettersson (1970). Grated crude tubers are pressed, and the juice is diluted with water (1:10), filtered, and stored in the dark at 6°C. The light extinction coefficient of the extract is determined at 530 nm at the beginning and during the next three to four days. The results are corrected for a standardized dry matter content of the tubers. The extinction coefficient after 48 hours is determined by a regression calculation. Modifications were published by Abele (1987): centrifugation of the extract (20 min at 6000 rpm), dilution at 1:19, and measurement at 400 nm.

Electrical conductivity of an extract. I received the details of this test, which like the previous one is applied to potato extract, from Pettersson as a personal communication several years ago. The extract is stored in the dark at 20°C for daily readings of electrical conductivity for at least six days. The final result is $C_D/C_0) \times 100$, where C_0 is the conductivity at the beginning and C_D is the difference between the highest reading and C_0.

Storage experiments. In this paper, this term is applied to experiments in which complete, undestroyed vegetables are stored for several months under conditions that are realistic in farming practice (e.g., Abele, 1987): 4-15°C; relative humidity almost 100%. These are called "favorable conditions," in contrast to degradation tests, in which cut or grated vegetables are kept at room temperature or even warmer for between several days and two weeks, as described above. Sometimes both kinds of tests have been carried out in parallel; Abele (1987) observed that more pronounced differences occurred under so-called unfavorable test conditions. That is why he modified degradation tests somewhat by incubating samples in plastic bags or preserving jars (see below).

The Fertilization Trial at Darmstadt

Most of the studies reported here used vegetable and cereal samples from a long-term trial carried out at Darmstadt, Germany. The trial has two variables: type and level of fertilization. The types are: composted cattle manure and urine, composted cattle manure and urine of the same origin but with application of all biodynamic manure and field preparations, and mineral fertilizer. In the first period (1980-1984), the levels were in the ratios 50%, 100% and 150%, and the manure amounts were selected with the aim of achieving yields comparable to those achieved with the corresponding levels of mineral fertilization. In the second period (1985 to the present), the fertilization has been based on applying equivalent amounts of total N with all types of fertilizer. The three levels are 60, 100, and 140 kg N/ha on cereals, and 50, 100, and 150 kg N/ha on vegetables. Details of the experiment have already been published (Abele, 1987; Raupp, 1995; Bachinger, 1996).

Summary of Results

Some results of the Darmstadt fertilization trial and other studies are summarized in the following as far as their relevance to the quality tests.

First period (1980-1984)

The aim of getting comparable yields in the organic and mineral treatments can be regarded as achieved. As a rule, the nitrate contents of carrots (*Daucus carota*), red beets (*Beta vulgaris*), and potatoes were much lower with manure than with mineral fertilization (Abele, 1987). On average over four years, carrots grown with composted manure had nitrate levels (fresh weight basis) of 109 and 119 ppm with and without biodynamic preparations, respectively, compared with 199 ppm in the mineral treatment. In red beets the corresponding values were 973 and 962 ppm compared with 1315 ppm, and in potatoes 99 and 95 ppm compared with 162 ppm. With all crops and in all years, the maximum values were higher with the mineral fertilizer than with the manure.

Degradation tests were carried out with the vegetables. Because of technical and workload reasons it was impossible to do all tests in every year with every crop. The only consistent effects of fertilization observed across crops and years involved microbial infestation of the samples, with the minerally fertilized vegetables showing higher infestation. The minerally fertilized carrots became dark brown and the tissue was partly dissolved, whereas with the manure treatments the carrots showed only some small brown patches (Abele, 1987, pp. 215-216). The dry matter losses of minerally fertilized carrots during degradation were higher than with both manure treatments (Abele, 1987, p. 50).

With red beets the degradation tests gave similar results regarding microbial infestation (Abele, 1987, pp. 219-220). However, dry matter losses of the grated beets in the degradation test did not vary with type of fertilization, and respiration activity during degradation (measured in 1983 and 1984) showed the opposite order in the two years. As with carrots, no clear differences in respiration occurred in storage experiments with beets (optimal conditions).

With potatoes a degradation test was carried out in one year (1981), with tuber pieces stored in preserving jars at room temperature; the same differences in favor of organic fertilization were observed as with carrots and red beets (Abele, 1987, p. 223). Further degradation tests (at 20°C)

corroborated the results with carrots and red beets, as no clear effects of fertilization occurred regarding dry matter loss (measured in 1983) or respiration (1983 and 1984). Darkening of potato extract showed clear differences only toward the end of the test; after 24 hours the minerally fertilized samples were darker.

With respect to the bread baking process, Abele (1987) investigated the density of useful microorganisms on rye (*Secale cereale*) samples. In a mixture of rye meal and water the numbers of *Lactobacillus* organisms and yeasts were counted. Afterwards the same counts were made in the sourdough originating spontaneously from the setup mixture kept warm for three days. Overall, the population densities were higher with both manure treatments; in many cases there was an additional increase with the biodynamic preparations.

Second period (1985 to present)

Yields were higher with mineral than with organic fertilization: an average of 27.3 vs. 24.6 t/ha for potatoes and 3.6 vs. 2.7 t/ha for rye. In contrast, spring wheat (*Triticum aestivum*) had about the same yield (3.5 t/ha) with organic and mineral fertilization (Raupp, 1997). Increasing fertilization levels caused higher yields with all crops. The application of biodynamic preparations increased potato yields on average by 1.6 t/ha.

Similar degradation tests as in the first period were carried out during the later years, such as with potatoes in 1993 (Sabiwalsky, 1995). In agreement with the results reported above, no substantial differences occurred in dry matter loss, but differences were apparent in the extract darkening after 48 hours (Abele did his last reading after 24 hours). The extracts of tubers from minerally fertilized plants were darker than extracts of the manure treatments. Increasing fertilization levels also caused more intensive darkening of the extracts. A much darker juice also was found in another study comparing conventional and biodynamic potatoes in a nine-year trial in Sweden (Pettersson, 1982).

In Darmstadt, organic fertilization also gave lower electrical conductivity values, but the differences compared with the minerally fertilized samples were significant only on day 3. Conductivity also was increased by higher amounts of fertilizers. Potatoes grown in the next year showed differences in extract conductivity that were in the same direction but smaller, and not significant on most dates (Schulz and Köpke, 1995).

The red beets of the Darmstadt experiment in 1985 and 1986 were investigated after harvest in autumn and the following spring after storage (Hermanns-Sellen, 1989). Because of a crop failure in 1985 (damage by hail and nematodes), only the results of 1986 are considered. In a storage experiment, durability was evaluated as the ratio of rotted to healthy red beet tissue after 4.5 months at low temperature. With the mineral treatment, the spoilage loss of 4% was considerably lower than with manure fertilization (13 and 19%). The nitrate content was much higher after mineral fertilization, 33 mg/g (dry weight basis) compared with 21 and 26 mg/g. The free amino acid contents differed in the same way, 42 mg/g (dry weight basis) in the mineral but only 13 and 16 mg/g in the manure treatments. The dry matter losses in degradation tests were evaluated before and after storage. The values were around 33 to 34% in all treatments on both dates.

Discussion of the Quality Tests

A suitable test for food quality should use a parameter that is relevant to human nutrition, health, or well-being; if not immediately relevant, it should be possible to interpret it in relation to some relevant parameter. Moreover, the test should allow reproducible results with a reasonable effort. As long as a test is in the development stage, it may not fully meet these requirements. For example, the analytical effort might still be too high, or the significance for human health not completely understood. The tests in question here must be checked for these criteria.

Summarizing the observations discussed here, the degradation tests did not give the same results with all vegetable crops or in all years for the parameters used (dry matter loss, microbial infestation, carbon dioxide development). Degradation tests ("unfavorable" conditions) could distinguish samples better than storage experiments ("favorable" conditions). Microbial attack gave reproducible results more often than carbon dioxide development or dry matter loss during incubation.

As no inoculation was used, the infestation was caused by the microflora present when the test was started. With an unknown microflora, however, it is unclear which species of organisms were active and which product characteristics favored or hindered them in decomposing the sample material. This information would be very useful in several respects. It could help to explain the reasons for different degrees of infestation observed with different treatments; it could give indications of relevant resistance parameters of plant products against spoilage during storage; above all, it could help to optimize and standardize degradation tests based on microbial infestation.

The last point is an important condition for routine use of this degradation test and for drawing scientific conclusions from the observations. Without standardized conditions the test may fail, and without background information we can only state which treatment caused what degree of infestation, but not why. More effort should be invested in developing and standardizing degradation tests based on microbial attack, as this parameter is easy to determine and in most cases easy to interpret, and is highly reproducible with several products. In addition, the background of infestation needs to be clarified by investigating other biochemical and physical characteristics (e.g., protein composition, enzyme activities, cell and tissue structure and others used by Kerpen, 1988).

The results of microbial attack were not necessarily correlated with the results of dry matter loss or carbon dioxide development during incubation, because the latter two parameters are nonspecific characteristics of the degradation process. A high microbial infestation does not inevitably result in a high dry matter loss, because the vegetable material is partially transformed into microbial biomass. A high respiration activity of the microbes can be expected in this case. However, if carbon dioxide mainly originates not from microorganisms but from autolytic decomposition of the sample, a high rate may be observed

even though the microbial attack was low. It would be interesting to be able to distinguish between the two carbon dioxide sources, as the microbial path and the autolytic path can be regarded as different types of decomposition belonging to different quality aspects of the sample.

A heavy microbial attack on vegetables can be interpreted as an obvious sign of low quality, indicating a weak product with low storage ability. The situation is more complicated if the results of the sourdough test with rye are also considered. As described above, Abele (1987) evaluated the population densities of *Lactobacillus* and yeasts. Both groups of microorganisms play an important role in dough and bread production. Therefore, a large number in rye should be judged as positive, since this will make the production process easier or quicker, or will help improve it in another way. In vegetables, however, large numbers of microorganisms normally will be judged negatively.

The opposite interpretations of essentially the same finding are not a matter of microbiology, because the organisms involved can be the same in both cases. *Lactobacillus* species can produce sourdough with rye but also sour red beets or carrots. A positive or negative evaluation also cannot be determined from the plant or the plant product. If you asked the rye kernels or the carrots, they would always interpret microbial attack as negative, because to be attacked is to be digested; their lives would be damaged or destroyed by the microbes. It is only our personal human view of how a product will be used that decides whether heavy microbial colonization is positive (useful for production of foods or feeds, such as sourdough or silage) or negative (because decayed vegetables cannot be eaten or sold). Microbial infestation in degradation tests can be interpreted only from a human-oriented perspective. Further research is necessary to standardize the degradation tests so that it is more reliable, to find possible correlations with other product characteristics (that is, to have better human-oriented and product-related interpretations), and to learn why it sometimes gives results different from those of practical storage experiments.

How useful is the biochemical degradation parameter of darkening of potato extract? The results frequently are reproducible, but not always. The experiences reported here are difficult to compare, because the extinction coefficient was not determined in all studies at the same wavelength, and the most clear differences were not observed at the same time after the beginning of the test. Further methodological research and standardization is necessary. An advantage of the darkening parameter is that its physiological background is largely known, which makes it possible to relate the results to product vitality. Darkening is based on various enzymatic processes involving phenolic acids and oxygen (references cited by Brouwer, 1976). In destroyed tissue these reactions take place more easily or rapidly, or the dark substances are not effectively metabolized. For that reason, it can be regarded as a sign of a vital (or rather intact) tuber if it stays less colored after being destroyed or damaged. In this view, greater darkening means low vitality and low quality, although the role of phenol metabolism in plant physiology is not fully understood. Unfortunately, it has not yet been possible to find any correlations between darkening and other parameters of durability or vitality. The above-mentioned studies examined the darkening of raw potatoes. In other reports, darkening of cooked potatoes also was influenced by fertilization (Pettersson and Engqvist, 1964). Consumers do not like this discoloration. The significance of darkening of cooked potatoes for humans is not known definitely. Therefore, this parameter seems to indicate only visual but not necessarily nutritional quality.

Another biochemical parameter is the electrical conductivity of extracts. Increasing conductivity is assumed to be an indicator of decomposition of organic matter because of the formation of ions and charged molecules when protein, carbohydrates, and other compounds are mineralized. But this parameter is not specific regarding either the substances being decomposed or the active principles (enzymes, organisms), and the results cannot be interpreted with respect to these factors. It has been observed that conductivity rises quickly at the beginning of incubation. After several days a final level is reached and maintained. The reason might be that some mineralized substances are simultaneously used to synthesize other organic compounds that are less charged or uncharged. This part of the process is also poorly understood. Another question is why the results are poorly reproducible in different years, except for the effects of fertilization intensity. It can be assumed that the observed changes in conductivity are only partially known from the sample material, and that, particularly after several days, they also come from decomposition of the colonizing microbial population. This, however, would be a severe distortion of the test, as it gives information about the vitality of the microflora, not of the sample. Several problems must be solved to develop this parameter for quality assessment.

The aim of all these parameters is to describe a product's resistance to breakdown, and thereby to quantify its vitality or "life-intensity". This view is very much a human-oriented approach to food quality because it assumes that the strength of a product is the essential element of nutrition responsible for our own vitality and development. This is a new dimension beyond material-based analyses that describe food as a kind of building material and fuel for the human organism. To test for vitality raises the fundamental question of how this can be done. Resistance against microbial degradation seems to be a suitable way, but the test needs to be developed and improved. Further research should be supplemented by research on other parameters and tests of product vitality, such as picture-creating methods (Balzer-Graf and Balzer, 1988). These tests also need to resolve some problems regarding the methods and their interpretation. They also show no clear correlation with other analytical product characteristics, but could reveal cropping and processing influences (Balzer-Graf and Balzer, 1991; Knijpenga, 1995).

A common problem with all the parameters discussed here is our lack of knowledge about how they are connected or correlated with other characteristics of plant products. Even information concerning properties that are not directly relevant to food quality could contribute to a better understanding of the microbial and biochemical parameters and the message they

can give us about the samples. For example, the darkening of potato juice has no nutritional significance, but reflects the intensity of an enzymatic process that indicates an unstable product. Considering that the microbial colonization of living plants and plant parts is a very complicated, reciprocal action (a fact well known from plant pathology), we should not expect to find simple relationships between these parameters and analytical data, such as nitrate or vitamin content or protein composition. In addition, the first problem before seeking correlations would be to define suitable, commonly accepted standard quality parameters. But this should not prevent anybody from pursuing this path, which could provide very important information on plant physiology, yield development, plant-microorganism interactions, and some comprehensive quality parameters. However, trying to trace back these parameters by correlations with other standard parameters probably would be the wrong path not only for quality research, but also for our understanding of crop physiology and human nutrition, as it would hinder us from gaining fundamentally new perspectives on plant growth and food quality, and therefore would make it difficult to shift to new paradigms of nutrition. As outlined above, our view of food quality should be open to new aspects, criteria, and tests, and not restricted to those already commonly accepted.

Human-oriented quality criteria

Human priorities are the basis of all quality assessment, which is finally based on our own expectations and considerations of usefulness. This is true not only regarding product durability or decomposition, but also for parameters like vitamin C or nitrate content. All these, and many others, make sense only in relation to human or animal nutrition "what is needed and what is harmful". These aspects of product quality are defined primarily by human priorities, and in some ways are uniform, as human beings are, while on the other hand they vary with individual, cultural, and historical factors. The attitudes of an individual, a group, or a society influence whether the same substance is a delicious cheese or just milk that has gone bad. Thus, a product-oriented concept of quality is subordinated to (individual) human-oriented criteria.

If human-oriented (not product-oriented) criteria are used to decide whether degradation is positive or negative, it is impossible to interpret high and low degradation as generally negative or positive, respectively, that is, as an intrinsic quality parameter. Abele (1987, pp. 132-136) and some other authors, however, support the general view that less degradation of a product demonstrates its maturity, stability, and coming to rest. But this view of physiological harmony or disharmony in the product does not explain why microbial decomposition should mean maturity with rye and immaturity with carrots. Moreover, the harmony or disharmony should be verified by typical constituents of the product, for example inorganic and organic nitrogen compounds. However, the results of Hermanns-Sellen (1989) with red beets, as described above, showed that high contents of nitrate and free amino acids coincided with low spoilage losses, and vice versa. According to the concept that maturity and stability of a product is expressed by its well-balanced components, the higher nitrate and free amino acid contents should lead to poor durability, but the opposite occurred here.

Accepting the human and social dimension of food quality leads to elaborating and considering political, social, psychological and economic criteria and tests, even criteria that cannot be analyzed in the product itself, but lie outside it. This means that all circumstances and consequences of food production, processing, distribution and consumption systems need to be used as quality parameters, besides the product's composition. A comprehensive approach in this direction is the concept of Leitzmann and Sichert-Oevermann (1988), who present a system of different quality degrees, ranking products from "highly recommended" to "not recommended" ("avoid consuming if possible"). The ranking is based not just on nutritional aspects but also on environmental consequences, energy consumption, and other factors during production and processing.

At least in Europe this is still an unusual approach to food quality assessment. For industrial products, however, we are accustomed to consider not only the characteristics of the car, camera or computer itself but also of the process by which it has been made. If a car is painted with varnishes that do not contain heavy metals, if waste from scrap cars is reduced because some parts can be recycled, or if an energy-saving production technology was used, for example, such facts are accepted as quality characteristics of the product, even if no differences can be recognized in the car itself. Why is it that for food, only characteristics that can be analyzed in the product are normally accepted as quality parameters?

Acknowledgments. Most of the studies reported here are based on a fertilization trial started in 1980 as a research assignment of the German Federal Ministry of Agriculture, Bonn, to which we are grateful for the financial support granted in 1980 to 1984. Since 1985 the research projects have been supported mainly by foundations and other private institutions. We are sincerely grateful to the Mahle Foundation, Stuttgart, which contributed the major part of the financial support in the later years.

References

1. Abele, U. 1987. Produktqualität und Düngung: mineralisch, organisch, biologisch-dynamisch. (Product quality and fertilization: mineral, organic, biodynamic.) Angewandte Wissenschaft, Heft 345. Münster-Hiltrup, Germany.
2. Alvensleben, R. v., and M. Altmann. 1986. Die Nachfrage nach alternativen Nahrungsmitteln. (The demand for organic food.) Agrarwirtschaft 35:289-295.
3. Baade, E. 1987. Verhaltensweisen und Werthaltungen bei Käufern alternativ erzeugter Lebensmittel. (Behavior patterns and values of consumers of organically produced food.) In Report on a Workshop Held at Stuttgart-Hohenheim, Oct. 1-3, 1986. AID, Bonn, Germany. pp. 28-35.
4. Bachinger, J. 1996. Der Einfluß unterschiedlicher Dungungsarten (mineralisch, organisch, biologisch-dynamisch) auf die zeitliche Dynamik und die räumliche Verteilung von bodenchemischen und -mikrobiologischen Parametern der C- und N-Dynamik sowie auf das Pflanzen- und Wurzelwachstum von Winterroggen.

(Influence of different fertilization types "mineral, organic, biodynamic" on temporal dynamics and spatial distribution of soil chemical and microbiological parameters of C- and N-dynamics and on plant and root growth of winter rye.) PhD thesis, Univ. Giessen. Schriftenreihe Band 7, Institut für biologisch-dynamische Forschung, Darmstadt, Germany.

5. Balzer-Graf, U.R., and F.M. Balzer. 1988. Steigbild und Kupferchloridkristallisation: Spiegel der Vitalaktivität von Lebensmitteln. (Steep track picture method and copper chloride crystallization: a mirror of the vital activity of food.) In A. Meier-Ploeger, and H. Vogtmann (eds.). Lebensmittelqualität: ganzheitliche Methoden und Konzepte. (Food Quality: Holistic Methods and Concepts.) C.F. Müller, Karlsruhe, Germany. pp. 163-210.
6. Balzer-Graf, U.R., and F.M. Balzer. 1991. Milchqualität im Spiegel bildschaffender Methoden. (Milk quality reflected by picture-creating methods.) Lebendige Erde, Heft 5, 236-255.
7. Brouwer, W. 1976. Handbuch des speziellen Pflanzenbaues. Band II. (Manual of Crop Production. Vol. II.) Verlag P. Parey, Berlin and Hamburg, Germany.
8. Gransted, A., and L. Kjellenberg. 1997. Long-term field experiment in Sweden: Effects of organic and inorganic fertilizers on soil fertility and crop quality. In W. Lockeretz (ed). Agricultural Production and Nutrition. Proceedings of an International Conference. School of Nutrition Science and Policy, Tufts Univ., Medford, Massachusetts. pp. 79-90.
9. Hermanns-Sellen, M. 1989. Chemisch-physiologische Kennwerte und Lagerverhalten von organisch und mineralisch gedüngter Rote Bete eines Feldversuches. (Chemical and physiological parameters and storage ability of organically and minerally fertilized red beet from a field trial.) PhD thesis, Univ. Giessen, Germany.
10. Kerpen, J. 1988. Untersuchungen zum Vergleich von Möhren (*Daucus carota* L.) aus ökologischem und konventionellem Landbau. (Comparison of carrots from organic and conventional farming.) PhD thesis, Techn. Univ. Berlin, Germany.
11. Knijpenga, H. 1995. Veränderungen der Lebensmittelqualität bei der Konservierung durch Gammastrahlen. (Changes of food quality by preservation with gamma rays.) Ökologie & Landbau, Heft 2, 17-19.
12. Leitzmann, C., and W. Sichert-Oevermann. 1988. Lebensmittelqualität und Lebensmittelwahl nach Wertstufen. (Food quality and food choice according to levels of value.) In A. Meier-Ploeger and H. Vogtmann (eds). Lebensmittelqualität: ganzheitliche Methoden und Konzepte. (Food Quality: Holistic Methods and Concepts.) C.F. Müller, Karlsruhe, Germany. pp. 45-66.
13. Meier-Ploeger, A., 1995. Das lebende Ganze ist mehr als die Summe seiner Teile. (The living whole is more than the sum of its parts.) Ökologie & Landbau, Heft 94, pp. 6-11.
14. Meier-Ploeger, A., and H. Vogtmann (eds), 1988. Lebensmittelqualität: ganzheitliche Methoden und Konzepte. (Food Quality: Holistic Methods and Concepts.) C.F. Müller, Karlsruhe, Germany.
15. Pettersson, B.D. 1970. Verkan av växtplats, gödsling och tillväxtreglerande substanser på matpotatisens kvalitetsegenskaper. (Effect of site, fertilization and growth regulating substances on quality parameters of potatoes.) Nordisk forskningsring Meddelande nr 23.
16. Pettersson, B.D. 1982. Konventionell und biologisch-dynamisch erzeugte pflanzliche Nahrungsstoffe im Vergleich. (Comparison of conventionally and biodynamically produced vegetable foods.) Angewandte Wissenschaft, Heft 263, pp. 218-228.
17. Pettersson, B.D., and M. Engqvist, 1964. Die Auswirkungen der Düngung auf die Qualitätseigenschaften von Kartoffeln. (Fertilization effects on quality parameters of potatoes.) Lebendige Erde, Heft 5, pp. 199-219.
18. Raupp, J. 1995. The long-term trial in Darmstadt: Mineral fertilizer, composted manure and composted manure plus all biodynamic preparations. In J. Raupp (ed). Main Effects of Various Organic and Mineral Fertilization on Soil Organic Matter Turnover and Plant Growth. Proc. 1st Meeting Concerted Action Fertilization Systems in Organic Farming (AIR3-CT94-1940), Darmstadt, May 1995. pp. 28-36.
19. Raupp, J. 1997. Yield, product quality and soil life after long-term organic or mineral fertilization. In W. Lockeretz (ed). Agricultural Production and Nutrition. Proceedings of an International Conference. School of Nutrition Science and Policy, Tufts Univ., Medford, Massachusetts. pp. 91-101.
20. Sabiwalsky, B. 1995. Untersuchung ausgewählter Parameter zur Beschreibung des Nacherntеverhaltens von Kartoffelknollen: Abhängigkeit von unterschiedlicher Düngungsart und -intensität sowie der Behandlung mit biologisch-dynamischen Präparaten. (Investigation of selected parameters to describe post harvest behaviour of potato tubers depending upon different types and intensities of fertilization and application of biodynamic preparations.) Diplomarbeit, Institut für Organischen Landbau, Univ. Bonn, Germany.
21. Samaras, I. 1978. Nacherntеverhalten unterschiedlich gedüngter Gemüsearten mit besonderer Berücksichtigung physiologischer und mikrobiologischer Parameter. (Post-harvest behaviour of vegetable crops with varying fertilization, with special consideration of physiological and microbiological parameters.) PhD thesis, Univ. Giessen. Publications Lebendige Erde, Darmstadt, Germany.
22. Samaras, F. 1981. Die epiphytische Mikroflora in Beziehung zu einigen biochemischen Merkmalen und zu einigen Kriterien der Verderbnisanfälligkeit ausgewählter Nahrungspflanzen, insbesondere Getreide. (The epiphytic microflora in relation to some biochemical characteristics and to some criteria of spoilage susceptibility investigated with selected food crops, mainly cereals.) PhD thesis, Univ. Giessen. Publications Lebendige Erde, Darmstadt, Germany.
23. Schulz, D.G., and U. Köpke. 1995.

Effects of intensified mineral and organic fertilizer and biodynamic preparations on yield, quality and shelf life of potatoes. In J. Raupp (ed). Main Effects of Various Organic and Mineral Fertilization on Soil Organic Matter Turnover and Plant Growth. Proc. 1st Meeting Concerted Action Fertilization Systems in Organic Farming (AIR3-CT94-1940), May 1995, Darmstadt, Germany. pp. 42-47.

24. Spiess, H. 1978. Konventionelle und biologisch-dynamische Verfahren zur Steigerung der Bodenfruchtbarkeit. (Conventional and biodynamic methods to increase soil fertility.) PhD thesis, Univ. Giessen. Publications Lebendige Erde, Darmstadt, Germany.
25. Wirthgen, B. 1987. Zum Konsumverhalten der Käufer alternativ erzeugter Nahrungsmittel in Nordhessen. (Consumption behavior of buyers of organically produced food in North Hessia.) In Report on a Workshop Held at Stuttgart-Hohenheim, Oct. 1-3, 1986. AID, Bonn, Germany. pp. 20-27.
26. Wistinghausen, E. v. 1979. Was ist Qualität? Wie entsteht sie und wie ist sie nachzuweisen? (What is quality? How does it arise and how can it be proved?) Verlag Lebendige Erde, Darmstadt, Germany.
27. Wistinghausen, E. v. 1984. Düngung und biologisch-dynamische Präparate. (Fertilization and biodynamic preparations.) Verlag Lebendige Erde, Darmstadt, Germany.

RESOURCES

"Composting for Manure Management" is $39 from *BioCycle,* 419 State Ave., Emmaus, PA 18049; (610) 967-4135.

20 New Reports by the National Water-Quality Assessment Program, U.S. Geological Survey, summarize findings about water quality in 20 major river basins: Albemarle-Pamlico Drainage, Apalachicola-Chattachoochee-Flint Rivers, Central Columbia Plateaus, Central Nebraska Plateaus, Connecticut-Housatonic and Thames Rivers, Georgia-Florida Coastal Plain, Hudson River, Lower Susquehana River, Las Vegas Valley-Carson and Truckee Rivers, Ozark Plateaus, Potomac River, Red River of the North, Rio Grande Valley, San Joaquin-Tulare Rivers, South Platte River, Trinity River, Upper Snake River, Western Lake Michigan Drainage, White River, and Willamette River; they are available on the Internet at http:water.usgs.gov, then click on NAWQA, or from the NAWQA program at (703) 648-5716; e-mail nawqa whq@usgs.gov

"The Organic Pages, 1998 North American Resource Directory" is $44.95 plus $6 shipping; "Organic Cotton Directory" is $15 plus $3 shipping from Linda Lutz, Organic Trade Association, P.O. Box 1078, Greenfield, MA 01302; (413) 774-7511.

"Generic Materials List," published by the Organic Materials Review Institute, is available by subscription or as a product review from OMRI, Box 11558, Eugene, OR 97440; (541) 343-7600.

"A Guide to USDA and Other Federal Resources for Sustainable Agriculture and Forestry Enterprises" is free from the Appropriate Technology Transfer for Rural Areas, P.O. Box 3657, Fayetteville, AR 72702, (800) 346-9140; e-mail askattra@ncatark.uark.edu; on the Internet at http://www.attra.org

"Small Farm Resource Guide" is available from USDA-Cooperative State Research, Education and Extension Service, Plant and Animal Systems, Stop 2220, 1400 Independence Ave., SW, Washington, D.C. 20250; (202) 401-4385; e-mail sfp@reeusda.gov; or on the Internet at http://www.reeusda.gov/smallfarm

"The Monitoring Tool Box" is $35 plus $7 shipping/handling from Land Stewardship Project, P.O. Box 130, Lewiston, MN 55952; (507) 523-3366.

"The Greatest Story Never Told: The Food Miracle in America," the text of the 1998 Henry A. Wallace Annual Lecture by Hugh Sidey, Contributing Editor, *Time* Magazine, is $5 from the Wallace Institute, 9200 Edmonston Road, Greenbelt, MD 20770; (301) 441-8777.

"Hungry for Profit: Agriculture, Food and Ecology," a special double issue of *Monthly Review* co-edited by Fred Magdoff, a member of the Wallace Institute's Board of Directors, is $10 plus $3 postage from *Monthly Review*, 122 West 27th St., New York, N.Y. 10001.

Resources from the Sustainable Agriculture Network include **"Steel in the Field: A Farmer's Guide to Weed Management Tools,"** $18; **"Managing Cover Crops Profitably,"** $19; **"Sustainable Agriculture Directory of Expertise,"** $18.95; **"Source Book of Sustainable Agriculture,"** $12; and **"The Real Dirt: Farmers Tell About Organic and Low-Input Practices in the Northeast,"** $13.95; all are available from SAN Publications, Hills Building, Room 12, University of Vermont, Burlington, VT 05405-0082; (802) 656-0471; e-mail nesare@zoo.uvm.edu

"Integrated Pest Management for Tomatoes," an illustrated manual, is $30; **"Specialty and Minor Crops Handbook, Second Edition"** is $42.89; both are available from University of California, DANR Communication Services-Publications, 6701 San Pablo Ave., Oakland, CA 94608; 1-800-994-8849; e-mail danrcs@ucdavis.edu

"Water Quality in the San Joaquin-Tulare Basins, California 1992-95" is free from USGS California District Office, Placer Hall, 6000 J St., Sacramento, CA 95819; (916) 278-3000; an order form is on the Internet at http://www-nmd.usgs.gov/esic/to order.html

"Sustainability Assessment in Agriculture: Annotated Bibliography and Resource List of Methods" is available from Luanne Lohr, Assistant Professor, Department of Agricultural and Applied Economics, 301 Conner Hall, University of Georgia, Athens, GA 30602-7509.

"Integrated Pest Management Program," the 1998 Annual Report of the New York State IPM Program, is free from NYS IPM Program, NYSAES, Geneva, N.Y. 14456; (315) 787-2353, or on the Internet at http://www.nysaes.cornell.edu/ipmnet/ny/

"The Economic Merit of Animal Manures as a Source of Plant Nutrients or Energy Generation" is $13 from UC Agricultural Issues Center, University of California, Davis, CA 95616; (530) 752-2320.

"Whole Farm Planning: Combining Family, Profit and Environment" is $2.50 from Minnesota Institute for Sustainable Agriculture, 1-800-876-8636.

Guide for Authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multidisciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

Units

Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of the authors; 3) affiliation and office address of authors, and 4) disclaimers and publication number, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single-discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key Words

Provide subject matter key words suitable for use in scientific indexing.

Reference List

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized.

Citing References

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript Preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Every figure and table should be mentioned at least once in the text.

A detailed guide to formatting is available from the editor (address below).

Submission of Manuscripts

Submit four high-quality copies to Dr. Robert I. Papendick, Editor, American Journal of Alternative Agriculture, Department of Crop & Soil Science, 253 Johnson Hall, Washington State University, Pullman, WA 99164-6420. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form, that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of family farms and rural communities.

Alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, enhanced environmental quality, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Henry A. Wallace Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

The Wallace Institute also provides these services:

- *A resource to lawmakers and others who influence agricultural research, education, and information policy*
- *A voice for alternative agriculture in Washington*
- *A sponsor of research and education outreach programs*
- *A national clearinghouse for information on alternative agriculture*
- *A publisher of reliable scientific information on agricultural sustainability*

If you're interested in helping us, please contact the Henry A. Wallace Institute for Alternative Agriculture, 9200 Edmonston Road, Suite 117, Greenbelt, Maryland 20770-1551. Telephone: 301-441-8777; E-mail: hawiaa@access.digex.net; Web site: www.hawiaa.org

HENRY A. WALLACE INSTITUTE
FOR ALTERNATIVE AGRICULTURE